

# **BEYOND DEMONSTRATION:**

## **THE ROLE OF FUEL CELLS IN DoD'S ENERGY STRATEGY**



Report Documentation Page				Form Approved OMB No. 0704-0188	
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1. REPORT DATE <b>19 OCT 2011</b>		2. REPORT TYPE		3. DATES COVERED	
4. TITLE AND SUBTITLE <b>Beyond Demonstration: The Role of Fuel Cells in DoD's Energy Strategy</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) <b>Thomas Gross; Albert Poche, Jr. ; Kevin Ennis</b>				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>LMI,2000 Corporate Ridge,McLean,VA,22102-7805</b>				8. PERFORMING ORGANIZATION REPORT NUMBER <b>DES11C1</b>	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited.</b>					
13. SUPPLEMENTARY NOTES <b>The original document contains color images.</b>					
14. ABSTRACT <b>The Defense Logistics Agency (DLA) sponsored an assessment of how fuel cells can help meet DoD's power needs in the near term, i.e., the next 5 years. The assessment is intended to assist DoD in establishing priorities and taking actions that reflect the potential energy, environmental, and economic benefits of fuel cells; the current fuel cell readiness to support DoD missions; and DoD's role as an early adopter of technology. The value proposition of four applications was analyzed, and recommendations for DoD action were developed. This report provides an overview of the assessment.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES <b>50</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			



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# **BEYOND DEMONSTRATION: THE ROLE OF FUEL CELLS IN DoD'S ENERGY STRATEGY**

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On the Front Cover:

From left to right: FCE Fuel Cell System, MCB Camp Pendleton, CA (Courtesy of PAO Camp Pendleton); MHE powered by Plug Power fuel cells, DLA Distribution Susquehanna, PA (Courtesy of Defense Logistics Agency); Plug Power fuel cell backup power system (Courtesy of LOGANEnergy); RQ-4 Global Hawk UAV (Courtesy of Air Force Intelligence, Surveillance and Reconnaissance Agency)

Note:

This report was sponsored by the Defense Logistics Agency Research and Development (DLA R&D).

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# EXECUTIVE SUMMARY

The Department of Defense (DoD) is a leader in the research, development, and demonstration of fuel cell technologies. Its support has contributed to significant improvements in fuel cell performance and reliability.

The question at issue is whether DoD should view fuel cells as a competitive, valuable, and appealing alternative for meeting its electric power needs within the next 5 years. Should fuel cells be a DoD “technology of choice” in the near future? If so, should the department act to ensure their consideration when it acquires energy services, power production equipment, and power-using equipment? Should the acquisition and use of fuel cells move beyond development and demonstration projects?

We define 11 potential fuel cell applications for DoD and focus on 4 of those. We conclude that **DoD should more proactively evaluate and acquire fuel cell systems** for three of the applications:

1. **Distributed power generation.** All or a portion of base load power, as well as heating and cooling needs, can be provided by fuel cell systems. As an option for supplying facility energy services, fuel cells can increase energy efficiency and reduce operating costs, building energy intensity, and emissions.
2. **Backup power.** Military facilities are highly dependent on a vulnerable commercial power grid. Backup power systems eliminate risks from grid disruption. As an option for backup power, fuel cell advantages include reliability, lower maintenance, longer life, lighter weight, and lower emissions.
3. **Unmanned vehicles.** Growth is expected in DoD use of unmanned vehicles. As an option for powering these vehicles, and based on demonstration results, fuel cells have excellent potential to improve mission capability.

The fourth application of particular interest for near-term routine acquisition of fuel cell systems is non-tactical material handling equipment. For some private sector customers, there is a growing preference for fuel cell powered equipment. DoD should continue to monitor the costs and benefits of introducing this technology in appropriate distribution operations.

Commercial fuel cell products are available for the four applications addressed in this report. Based on their value proposition, increasing quantities of these products are currently being manufactured and sold to private-sector customers.

DoD paid about \$4 billion for facilities energy in 2009. Electricity accounted for 64 percent of the energy consumption at DoD installations, which used about five times the amount of electricity consumed by all customers in the state of Ver-

mont. Legislative mandates, executive orders, and DoD policies have established aggressive targets for energy use and emissions reductions.

## Recommendations

We recommend that DoD headquarters organizations and the military services:

- ▶ Monitor and evaluate government and private-sector fuel cell projects.
- ▶ Independently and in conjunction with other federal agencies, particularly the Department of Energy, continue support for research, development, and demonstration of fuel cells and the fuels required for their operation.
- ▶ Continue defining and pursuing fuel cell partnership initiatives with the Department of Energy.
- ▶ Develop and implement procurement models that enable increased visibility for fuel cell options in competitive solicitations; more efficient acquisition of fuel cell systems; and realization of the potential benefits of third-party financing of fuel cell systems.
- ▶ Require that fuel cell systems be considered for meeting electric power, heating, and cooling demands whenever any new facilities and major renovations are planned and designed; and that respondents to solicitations for locally produced power consider fuel cell systems.
- ▶ Require that fuel cell systems be considered during planning and designing backup power capability for a DoD site; and that respondents to solicitations for backup power consider fuel cell systems.
- ▶ Plan and implement an initiative to address the limitations of current power purchase models with respect to acquiring emerging technologies, including fuel cells.
- ▶ Invite, but not require, bidders for material handling equipment to consider fuel cell power.
- ▶ Increase awareness of unmanned vehicle designers, providers, and operators about fuel cell systems as an option for providing power.

Fuel cell technologies relevant for all applications of interest to the Department of Defense are maturing. DoD can benefit by tracking technological and commercial progress, so that it can promptly use the capability of fuel cells to contribute to its goals and missions.



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# CHAPTER I

## INTRODUCTION

Consistent with its mission responsibilities for procuring Department of Defense (DoD) fuels, the Defense Logistics Agency (DLA) supports initiatives to better understand the merits of hydrogen and other alternative fuels. DLA has extensive experience developing and demonstrating non-conventional fuels for a variety of applications. Given its interest in reducing DoD fuel use requirements, DLA also leads activities to advance more energy-efficient technologies, including fuel cells. DLA is one of multiple organizations within DoD and the military services that have made significant investments in hydrogen and fuel cell technologies.

In conjunction with its support for fuel cell development and demonstration, DLA has sponsored an assessment of how fuel cells can help meet DoD's power needs in the near term. This assessment is intended to assist it, and other organizations within DoD, in establishing priorities and taking actions that reflect

- the potential energy, environmental, economic, and operational benefits of fuel cells;
- current fuel cell readiness to support DoD missions; and
- DoD's role as an early adopter of technology.

Chapter 2 gives an overview of DoD fuel cell applications, activities, and issues. Chapters 3 through 6 are devoted respectively to four applications deserving particular attention during the next few years:

- Distributed power generation
- Non-tactical material handling and ground support equipment

- Backup power
- Unmanned vehicles.

### DoD ENERGY USE

DoD is the largest consumer of energy in the country,<sup>[1]</sup> accounting for approximately 80 percent of the federal government's energy consumption<sup>[2]</sup> and 1.6 percent of the nation's total energy use.<sup>[3]</sup> The primary source for meeting DoD's energy demand is petroleum, which provided 77 percent of all requirements in FY09 (Figure I-1). Electricity, which met 12 percent of the FY09 demand, is the next largest source.

In FY09, 57 percent of DoD's petroleum consumption, and 78 percent of the energy required for military operations, was jet fuel, which is used primarily for aircraft operations (Figures I-1 and I-2). The second largest source of operational energy is Navy Special Fuel, also a petroleum product and used primarily for ship propulsion.

Electricity supplied about 64 percent of the energy required for DoD installations during FY09. Natural gas provided another 15 percent (Figure I-2). For fleet vehicles (primarily cars and trucks), gasoline provided 71 percent of the FY09 fuel demand. Diesel fuel accounted for another 21 percent.

Information on DoD's FY09 energy consumption appears in Figures I-1 through I-3. The applications covered in this paper—those with high potential for near-term use of fuel cells by DoD—will not impact the department's dependency on petroleum to support its military operations. However, fuel cells could contribute significantly during the next 5 years to meeting installation energy mandates and goals.

Figure I-1 DoD Energy Consumption (Btu), FY09<sup>[4]</sup>

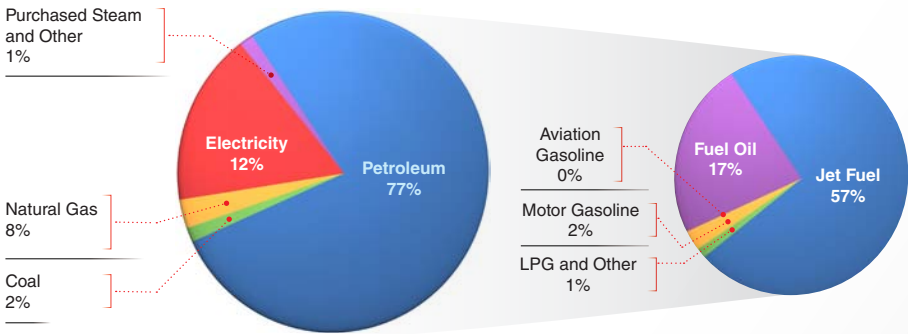


Figure I-2

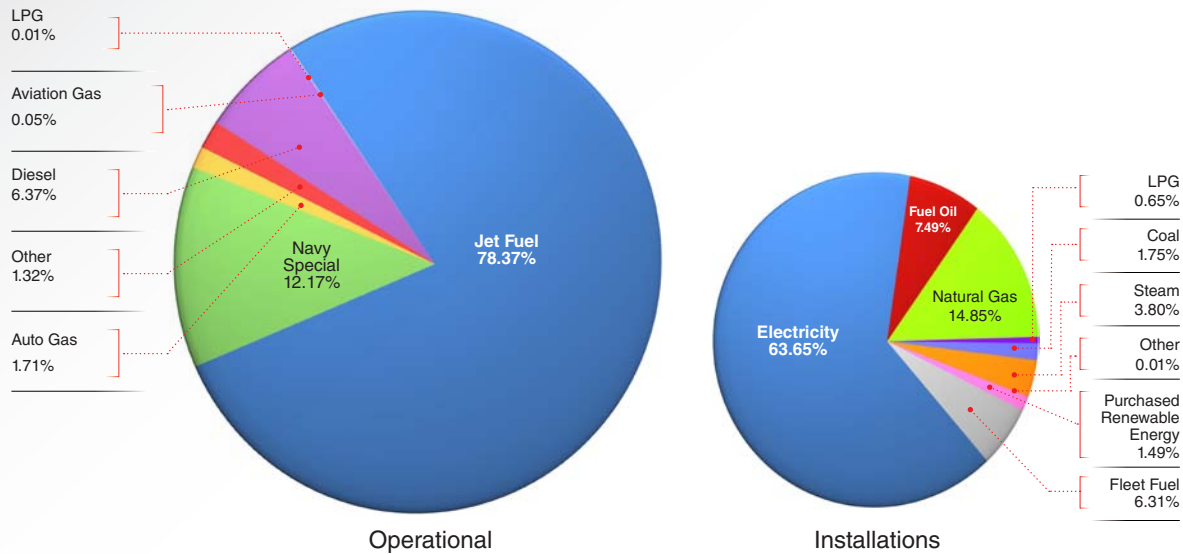
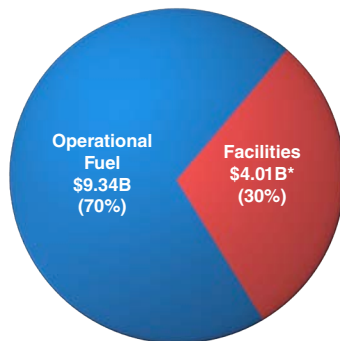
DoD Energy Use Breakdown, FY09<sup>[5]</sup>

Figure I-3

DoD Energy Costs, FY09<sup>[6]</sup>

\*\$4.01B in facilities energy costs include non-tactical vehicle fuel:  
 \$3.78B - facilities energy  
 \$0.225B - non-tactical vehicle fuel

## ► ENERGY DIRECTIVES AND GOALS

Laws, directives, policies, and regulations influence DoD's energy use and environmental impact. The following discussion summarizes those having particular relevance for DoD's energy strategy, including the acquisition of fuel cells.

### FEDERAL LAWS AND EXECUTIVE ORDERS

- *The National Energy Conservation Policy Act (NECPA)*. Signed in November 1978, this authorizes federal energy management programs, goals, and requirements. NECPA has been amended and updated by subsequent laws and regulations. The fully amended law pertaining to energy management by federal agencies is at Title 42 of the U.S. Code, Chapter 91, Subchapter III, Part B.<sup>[7]</sup>
- *The Energy Policy Act of 1992 (EPAc 1992)*.<sup>[8]</sup> Among other provisions, EPAc 1992 gives federal agencies authority to enter into energy savings performance contracts (ESPCs) for the purpose of achieving energy savings.
- *EPAc 2005*.<sup>[9]</sup> EPAc 2005 mandates that new federal buildings be designed to ensure that energy use is 30 percent lower than the American Society of Heating, Refrigeration and Air Conditioning Engineers 90.1 (2007) standard or the International Energy Code. Authorization for using ESPCs was extended through September 30, 2016.
- *Executive Order (EO) 13423, Strengthening Federal Environmental, Energy, and Transportation Management*. Signed in January 2007, this established energy and environmental goals in several areas.<sup>[10]</sup> EO 13423 requires that federal agencies reduce energy intensity by 3 percent annually, leading to 30 percent by the end of FY15, relative to a FY03 baseline.
- *The Energy Independence and Security Act (EISA)*.<sup>[11]</sup> Signed in December 2007, EISA established energy management goals and requirements. It adopts the energy intensity reduction goals of EO 13423; stipulates that federal buildings be designed to reduce fossil fuel-generated energy consumption; and requires that sustainable design principles be applied to siting, design, and construction of buildings. The period for life-cycle cost calculations was increased from 25 to 40 years.

- *EO 13514, Federal Leadership in Environmental, Energy and Economic Performance*.<sup>[12]</sup> Signed in October 2009, EO 13514 expands the energy reduction and environmental performance requirements of EO 13423. It requires that all new construction, major renovations, repairs, or alterations of federal buildings comply with the Guiding Principles of Federal Leadership in High Performance and Sustainable Buildings. It also requires establishment of reduction targets for greenhouse gas (GHG) emissions.

**“UNLEASHING WARFIGHTERS FROM THE TETHER OF FUEL AND REDUCING OUR INSTALLATIONS’ DEPENDENCE ON A COSTLY AND POTENTIALLY FRAGILE POWER GRID WILL NOT SIMPLY ENHANCE THE ENVIRONMENT, IT WILL SIGNIFICANTLY IMPROVE OUR MISSION EFFECTIVENESS.”**

Dorothy Robyn, Deputy Undersecretary of Defense for Installations and Environment, January 27, 2010.

### DoD POLICIES AND GUIDANCE

- *DoD-Department of Energy Memorandum of Understanding (MOU)*. Signed in July 2010, this MOU states that “DoD aims to speed innovative energy and conservation technologies from laboratories to military end users, and it uses military installations as a test bed to demonstrate and create a market for innovative energy efficiency and renewable energy technologies coming out of Department of Energy (DOE) laboratories, among other sources.”<sup>[13]</sup>
- *DoD Strategic Sustainability Performance Plan (SSPP)*. In August 2010 DoD issued its FY10 SSPP,<sup>[14]</sup> as required by EO 13514. This plan, which also refers to the department's 2010 Quadrennial Defense Review, defines DoD's sustainability goals and performance expectations for the next 10 years.

**“THE DEPARTMENT NOT ONLY COMMITS TO COMPLYING WITH ENVIRONMENTAL AND ENERGY STATUTES, REGULATIONS AND EXECUTIVE ORDERS, BUT TO GO BEYOND COMPLIANCE WHERE IT SERVES OUR NATIONAL SECURITY NEEDS.”**

Department of Defense Strategic Sustainability Performance Plan, August 2010.



# CHAPTER 2

## THE FUEL CELL OPTION

### ► FUEL CELL APPLICATIONS

As a first step in approaching this document, we identified fuel cell applications of interest to DoD, in part by obtaining recommendations from organizations with an interest in fuel cells. Analysis and feedback led us to define 11 distinct applications:

- 1. Soldier wearable and portable power
- 2. Remote sensors and surveillance
- 3. Distributed stationary power
- 4. Non-tactical material handling and ground support equipment (MHE/GSE)
- 5. Backup power
- 6. Auxiliary power units for ground vehicles, ships, and aircraft
- 7. Non-tactical light-duty vehicles
- 8. Mobile electric power
- 9. Power for ships
- 10. Unmanned air, ground, and underwater vehicles (UXVs)
- 11. Non-tactical personnel transport (buses).

For each of these applications, we drafted brief descriptions of current activities and initiatives. After further discussions with representatives of several DoD organizations, DOE, and the fuel cell industry, we selected 4 of the 11 for further attention. A primary consideration in the “down-selection” process was a decision to concentrate on applications with the greatest potential for fuel cells being DoD’s “technology of choice” for power production within the next 5 years (by 2016). We are focusing on these four applications:

Distributed stationary power
Non-tactical MHE/GSE
Backup power
UXVs

We cannot conclusively determine that fuel cell systems will or should be the preferred technology for any application, due to factors such as their higher capital cost and relatively brief operational history. Such a conclusion is sometimes rendered more difficult by the challenges of delivering the required fuels. Problem-free operation of the fuel cell types commonly used for some of the selected applications requires high-quality hydrogen.<sup>[15]</sup> However, research and development (R&D), including that supported by DoD, have resulted in significant progress over the past 2 decades.

Table 2-1 indicates factors that influenced our decision to select the 4 applications.

Table 2-1. Priority DoD Fuel Cell Applications—Selection Factors

APPLICATION	SELECTION FACTORS FOR FOCUSED ANALYSIS
Distributed stationary power	<ul style="list-style-type: none"><li>◆ Many fuel cell systems, employing a variety of fuel cell types and produced by multiple manufacturers, have been and are currently being demonstrated.</li><li>◆ Fuel cell systems are being successfully operated, by both DoD and private-sector customers, to meet large-scale base load power production requirements. Commercially available fuel cell products are proving successful in achieving customer satisfaction.</li><li>◆ Fuel cell systems can provide mission-essential power during an electrical grid disruption.</li><li>◆ Across all of DoD, there are potentially a large number of opportunities for using fuel cell systems in this application.</li><li>◆ The need for clean and silent on-site power generation to help meet energy security and mission assurance requirements.</li><li>◆ The growing experience base with design, manufacturing, and maintenance of fuel cell systems being operated commercially.</li><li>◆ Emissions reduction and sustainable renewable energy integration potential.</li><li>◆ Regulatory and executive order requirements pertaining to energy use in buildings.</li><li>◆ The ability of private-sector third-party financing to address the issue of higher initial cost for fuel cell systems.</li></ul>

Table 2-1. *Priority DoD Fuel Cell Applications—Selection Factors*

APPLICATION	SELECTION FACTORS FOR FOCUSED ANALYSIS
<b>Non-tactical MHE/GSE</b>	<ul style="list-style-type: none"> <li>◆ Many forklifts and other vehicles powered by fuel cells have been integrated into fleets and are being used to meet normal operational requirements.</li> <li>◆ Fuel cell forklifts are being successfully operated by both DoD and private-sector customers.</li> <li>◆ Fuel cells suitable for powering MHE/GSE are produced by multiple manufacturers.</li> <li>◆ With experience, fuel cell system performance and durability are improving.</li> <li>◆ Under the right conditions, such as high-volume operations, fuel cell powered equipment can help increase productivity and reduce operating costs.</li> <li>◆ Across all of DoD, a very large number of potential opportunities exist for using fuel cell systems in this application.</li> <li>◆ The experience base is growing for design, manufacturing, and maintenance of fuel cell systems being operated commercially.</li> <li>◆ This application aligns with regulatory and executive order requirements pertaining to DoD vehicle energy use and petroleum reduction.</li> </ul>
<b>Backup power</b>	<ul style="list-style-type: none"> <li>◆ Many fuel cell systems, produced by multiple manufacturers, have been installed to provide backup power.</li> <li>◆ Fuel cell systems are providing backup power for critical needs, such as call centers, emergency responders, and service centers.</li> <li>◆ Major telecommunications companies have deployed or are planning to deploy hundreds of fuel cells for backup power.</li> <li>◆ Fuel cell backup power systems have been installed or are planned at multiple DoD sites.</li> <li>◆ Electricity outages or interruptions can be very costly. A Defense Science Board report on energy has identified this issue as a major concern.</li> <li>◆ This application could reduce emissions and noise.</li> <li>◆ Maintenance requirements and system reliability are favorable.</li> <li>◆ Across all of DoD, a very large number of opportunities exist for using fuel cell systems in this application.</li> <li>◆ The experience base is growing for design, manufacturing, and maintenance of fuel cell systems being operated commercially.</li> </ul>
<b>Unmanned vehicles</b>	<ul style="list-style-type: none"> <li>◆ Mission benefits, such as weight reduction and mission duration improvement, can be achieved by replacing batteries with fuel cells.</li> <li>◆ Growth is expected in the number of unmanned vehicles that could use fuel cells.</li> <li>◆ Recent development and demonstration activities have documented success.</li> </ul>

## ► SUPPORT FOR FUEL CELL DEVELOPMENT

DoD has funded and managed work on fuel cells for many years. Precise data on total investments are not available. However, estimates are that DoD spent between \$44 million and \$60 million on research, development, testing, and evaluation of fuel cell technologies in FY10. The lower figure is the amount reported to the Government Accountability Office for its De-

cember 2010 report on DoD power source investments. The higher figure has been estimated by DoD staff. In addition to support for fuel cell development, the department's budget also includes funds for hydrogen R&D activities. Hydrogen production and storage R&D are important for implementing fuel cell systems, which require economical, high-purity hydrogen.

DoD's support for fuel cell technologies is planned and managed by multiple organizations throughout the department. Organizations with department-wide responsibilities, in partic-



ular the Defense Advanced Research Projects Agency (DARPA) and DLA, and each of the military services fund a variety of diverse projects. DoD's research, development, and demonstration portfolio includes the following activities, which relate to various fuel cell applications.

**Soldier wearable and portable power.** The Army and the Air Force are funding development of small, lightweight fuel cell power supplies that can extend soldier mission times. Development of portable power systems is also being supported by the American Recovery and Reinvestment Act of 2009, with project management by DoD.

- ▶ **UXVs.** Elements of the Air Force, Army, and Navy are managing research, development, and demonstration projects leading to fuel cell-powered unmanned vehicles. Projects include the Air Force's Puma unmanned aerial vehicle (UAV), the Army's Talon unmanned ground vehicle (UGV), and the Navy's Ion Tiger UAV. The Navy is supporting extensive work on unmanned underwater vehicles (UUVs) (see Chapter 6).
- ▶ **Non-tactical MHE/GSE.** DLA is funding demonstrations of fuel cell-powered forklifts at four DoD installations. The Air Force Research Laboratory (AFRL) manages demonstration and validation of fuel cells for powering ground support equipment such as aircraft tow vehicles and flight line maintenance vehicles (see Chapter 4).
- ▶ **Backup power.** Fuel cell systems for backup power have been deployed at Fort Jackson, SC. During 2011, fuel cells will be installed at Los Alamitos Joint Forces Training Base, CA, and the Marine Corps Logistics Base, Barstow, CA. The Army's Construction Engineering Research Laboratory (CERL) and AFRL are funding and managing fuel cell backup power demonstrations that will be operational at 10 other DoD sites in 2011 (see Chapter 5).
- ▶ **Auxiliary power units for ground vehicles, ships, and aircraft.** The Army's Tank-Automotive and Armaments Command supports development of fuel cell-based auxiliary power units that can operate using 100 percent JP-8 Army logistics fuel.
- ▶ **Non-tactical light-duty vehicles.** DoD users are demonstrating fuel cell cars at West Point, NY, Fort Belvoir, VA, Camp Pendleton, CA, and DoD facilities in Oahu, HI.
- ▶ **Mobile electric power.** The AFRL is developing a logistics fuel processor suitable for mobility operations. Its aim is to combine that technology with the fuel cell technologies being developed by other DoD services and DOE to produce

the next generation of mobile electric power generator systems.

- ▶ **Power for ships.** The Office of Naval Research is supporting R&D of diesel fuel reformer technology, which could potentially be used in conjunction with fuel cells for shipboard propulsion and auxiliary power requirements.
- ▶ **Distributed stationary power.** Navy, Marine Corps, and Army installations are host sites for fuel cell systems that provide base load power, while also using the fuel cell's waste heat (see Chapter 3).
- ▶ **Non-tactical personnel transport (buses).** A hybrid shuttle bus, powered in part by a fuel cell, has been operated since 2004 at Hickam Air Force Base, HI. A fuel cell bus will be demonstrated as part of DLA's pilot project at the Joint Base Lewis-McChord, WA.

## ▶ BEYOND DEMONSTRATION: THE FUTURE OF FUEL CELLS IN DoD

Multiple fuel cell applications have several issues in common. We discuss these issues in this section rather than under each individual application. They are

- ▶ the capital cost of fuel cell systems,
- ▶ institutional factors affecting adoption of new energy technologies,
- ▶ the value of public benefits,
- ▶ third-party financing of investments, and
- ▶ future manufacturing costs.

## CAPITAL COST

Fuel cell systems for on-site stationary power production are expensive. Fuel cell capital costs for backup power are more than those for competing backup systems. In addition, the capital cost of fuel cells for MHE/GSE is higher than the cost of batteries or internal combustion engines that power equipment with equivalent capability. This "first cost" issue is exacerbated by the high cost of hydrogen required for fuel cell operation, relative to the cost of other MHE/GSE fuels.



Government subsidies have been a key factor in the recent growth of domestic fuel cell markets for the applications we discuss. At the current state of development, high acquisition costs—in the absence of subsidies—can be difficult to offset by savings in operating and maintenance costs over the life of the equipment. From a financial perspective, the value proposition is therefore likely to depend on federal and state government incentives that are not directly available to DoD.

## INSTITUTIONAL FACTORS

Among DoD's agency-level organizations and the military services, many people have responsibilities for or influence decisions affecting energy. These include decisions relating to distributed power generation, acquisition of backup power systems, the purchase of material handling equipment, and power for unmanned vehicles. DoD personnel are committed to the department's mission and compliance with directives, including those related to energy. Some have helped make DoD a leader in achieving energy efficiency and alternative fuel use targets. However, they are handicapped by several factors that can militate against procurement of newer, more environmentally benign technologies. These include:

- ❶ the federal budget process, which emphasizes minimizing upfront capital costs and downplays later savings;
- ❶ energy prices, which do not fully reflect goals such as energy security, GHG reduction, and reduced vulnerability to electric grid disruptions; and
- ❶ a culture that highly values tried-and-true technologies, sometimes at the expense of potentially superior but somewhat risky alternatives.

These factors need not prevent DoD decision makers from choosing to pursue fuel cell systems, but they render such a decision more difficult than it otherwise would be. Recently the Secretary of the Army established the Energy Initiative Office, which is charged with building both technical and business case metrics for investments to achieve military installation energy goals and objectives.

DoD leadership recognizes the institutional challenges. For example, in 2009 Secretary Gates stated during congressional testimony that “entrenched attitudes throughout the government are particularly pronounced in the area of acquisition: a risk-averse culture, a litigious process, parochial interests, excessive and changing requirements, budget churn and instability, and sometimes adversarial relationships within the Depart-

ment of Defense and between Defense and other parts of the government.”<sup>[16]</sup>

**“THERE ARE TECHNOLOGIES AVAILABLE NOW TO MAKE DOD SYSTEMS MORE ENERGY-EFFICIENT, BUT THEY ARE UNDERVALUED, SLOWING THEIR IMPLEMENTATION AND RESULTING IN INADEQUATE FUTURE S&T INVESTMENTS.”**

Report of the Defense Science Board Task Force on DoD Energy Strategy,

“More Fight – Less Fuel,” February 2008.

## VALUE OF PUBLIC BENEFITS

Among the institutional deterrents to new energy technology, cited above, is that prices paid by energy customers, including DoD, do not reflect the true value of public benefits. Such benefits are those that would be realized by, for example, reducing dependency on imported oil, lowering GHG emissions, and reducing the risks associated with losing power for mission-critical operations. At issue is whether DoD, supported by budget decisions of Congress and the President, will receive additional resources based on valuations of these public benefits. Such appropriations could be used for acquiring technologies, such as fuel cells, that enable achievement of mandated energy goals and targets.

Regarding critical missions at installations, the Defense Science Board Task Force on DoD Energy Strategy found that “high performance building designs are generally underutilized and underfunded.”<sup>[17]</sup> It also concluded that DoD's efforts to improve facility energy efficiency are modest compared to what can be technically and economically justified; and that the risks of electric grid outage are not considered during installation planning and investment decisions. Given pressures for budget reduction, however, it will likely be even more difficult to make the case to spend more money now in order to realize benefits later.

## THIRD-PARTY FINANCING

As for all federal government entities, organizations within DoD cannot benefit directly from federal incentives and subsidies available for buying and using fuel cells. However, financing a fuel cell system can be arranged by a private-sector third party that can monetize incentives such as investment and production tax credits. The system can then be leased to a DoD

customer, which reimburses the third party in accordance with provisions of an energy savings performance contract or other agreement.

Alternatively, a DoD installation commander can purchase electricity and related services from a third-party project developer that builds, owns, and manages on-site power generation equipment. This is accomplished using an energy services agreement or a power purchase agreement. Depending on the situation, the private investor owner or operator may also be able to take advantage of renewable energy credits, with the resulting benefits passed along to the DoD energy customer.

Manufacturers of material handling equipment (such as forklifts), ground support equipment, and unmanned vehicles can apply applicable subsidies to their products that use fuel cells. This benefit can then be reflected in a lower price for the equipment offered to customers, including DoD.

Further development of contracting models and procurement approaches could enable these concepts to be implemented more efficiently and with clear benefit for all parties.

## FUTURE MANUFACTURING COSTS

Opportunities for reducing costs are currently constrained by low demand. With further development and increasing sales, costs are expected to come down. A recent analysis by Battelle for DOE<sup>[18]</sup> concludes that the 2015 cost of a 5 kW fuel cell system for backup power applications could be about 60 percent of the 2010 cost. Anticipating that subsidies will not be available indefinitely, the fuel cell industry must continue to work intensively to reduce its product costs. Fuel cell manufacturers have indicated that continued government support for cost reduction activities is important.

DoD and its resource appropriators must decide whether to pay the additional costs of being an early adopter and leader in helping create a “commercial” market for fuel cell technology, or to wait for further progress.



# CHAPTER 3

## DISTRIBUTED STATIONARY POWER

### ► RATIONALE FOR FUEL CELLS

Distributed stationary power refers to systems that provide primary base load power for buildings, retail stores, manufacturing operations, data centers, and other facilities. Generally these systems can simultaneously produce thermal energy to satisfy a variety of needs such as space heating, water heating, and process heating. Combined heat and power (CHP) systems with fuel cells as the prime mover offer efficiencies that can exceed 80 percent.<sup>[19]</sup> The increased efficiency of fuel cell co-generation systems, which take advantage of the waste heat generated by the fuel cell, can reduce energy use and operating costs compared with conventional systems.

Fuel cells have the potential to reduce emissions associated with traditional approaches to electric power generation and heat production. Stationary fuel cells that normally satisfy base load power demand can also satisfy backup power needs, such as in an emergency when grid power is interrupted, and can form the backbone of high-availability power systems designed to protect mission-critical and highly sensitive priority electric loads.

For the military, stationary fuel cell systems can provide ship services power while a ship is in port, thus offering grid independence, energy assurance, reduced emissions, and improved fuel use efficiency.

Several distributed renewable sources of energy offer an alternative to on-grid power generation. Although other options—such as solar, wind, geothermal, and hydroelectric—may help DoD meet its energy goals, a fuel cell system possesses certain qualities that could make it the technology of choice. In comparison with other clean (non-combustion) technologies, fuel cells can provide the following advantages:

- Higher energy conversion efficiency
- Power production independent of wind or sunshine
- Lower cost per unit of power produced
- A small land use footprint, less noise, and a low height profile.

### ► DoD FUEL CELL ACTIVITIES

During the mid-1990s, phosphoric acid fuel cell (PAFC) systems were installed and operated at 30 military installations across the United States under a DoD demonstration program. It was managed by the Army's Engineer Research and Development Center—CERL.<sup>[20]</sup>

A FuelCell Energy (FCE) Direct FuelCell 300 kW (DFC300) power plant is being installed for demonstration at the U.S. Marine Corps Air Ground Combat Center (MCAGCC) Twentynine Palms, CA. Under a project sponsored by CERL, the DFC300 is being linked with a 250 kW FCE system previously installed at MCAGCC by LOGANEnergy, a fuel cell services company. These two molten carbonate fuel cell (MCFC) plants will begin operating together in 2011.

Three FCE 250 kW fuel cells are providing power at the Marine Corps Base Camp Pendleton, CA. Two were placed in service in late 2007 and one in early 2008. These systems, also installed by LOGANEnergy, are providing base load power and heat.

The AFRL, in a project previously managed by the Air Force Advanced Power Technology Office, has supported development, testing, and demonstration of an FCE DFC300 MCFC system at Barksdale Air Force Base (AFB), LA. From May 2010 until early January 2011, this system was operated locally and independent of the grid to supplement the base's conventional electricity supply with continuous base load power. It provided electricity, heat, and water for dormitory residents on the base. It also was available to support Barksdale's critical operations during emergencies such as blackouts, natural disasters, and weather events.



FCE FUEL CELL SYSTEM, MCB CAMP PENDLETON, CA  
COURTESY OF PAO CAMP PENDLETON

During 2011, the DFC300 at Barksdale AFB is being relocated to the Army's Camp Parks Reserve Forces Training Area near Dublin, CA. Under a contract with CERL, the unit will provide electric power to Camp Parks for 3 years.

LOGANEnergy will purchase, install, and operate two DFC300 plants at the Naval Submarine Base in Groton, CT. These units will provide base load electricity, with byproduct heat being used to preheat boiler water.

A DFC300 power plant is installed at the Navy's Pacific Missile Range Facility in Kauai, HI. This unit, which uses propane fuel transported to the site, is expected to resume full operation in mid-2011. LOGANEnergy owns and operates the system, which will provide about 35 percent of the facility's electricity requirements. High-grade heat produced by the fuel cell will be processed through an adsorption chiller and used for air conditioning.

## ▶ OTHER FUEL CELL ACTIVITIES

UTC Power produces PAFC systems. The fuel for its systems is natural gas, which is reformed to produce hydrogen for the fuel cell. Its systems have demonstrated an operational life of over 70,000 hours in the field, and 95 percent availability.

The company offered a 200 kW system for sale beginning in 1991. This was the first to be used commercially. Since then more than 300 units have been installed throughout the world, in 19 countries on 6 continents. These included PAFC systems at U.S. military installations (see "DoD Fuel Cell Activities," above). UTC Power's fuel cells have run over 9 million operating hours in the field and have produced more than a billion kW hours of electricity at private-sector and government customer sites.

A 400 kW PAFC—the UTC Power PureCell Model 400 system—is currently being sold. A number of improvements were made relative to the previous products, enabling extension of stack life to 10 years. In March 2010, UTC Power announced that the Model 400 is certified to meet the latest emission standards of the California Air Resources Board (CARB), the strictest in the United States.

UTC Power PAFCs are providing power and heat at supermarkets, hospitals, hotels, schools, data centers, office buildings, industrial facilities, mixed-use buildings, apartment buildings, museums and zoos, and wastewater treatment plants.<sup>[21]</sup> Customers include the following:

- ▶ Whole Foods Market (stores in Connecticut and Massachusetts, with another installation planned in San Jose, CA); Price Chopper; Albertson's; and Star Market

- ▶ Coca-Cola Refreshments, Elmsford, NY (bottling plant); \$2 million in funding support was received from the New York State Energy Research and Development Authority (NY-SERDA)

- ▶ Connecticut Science Center, Hartford, CT

- ▶ Roberto Clemente School, New Haven, CT

- ▶ St. Helena's Hospital in Napa Valley, CA

- ▶ Hilton New York; this system was installed in October 2007; \$200,000 in funding came from the DoD Climate Change Rebate Project

- ▶ New York Power Authority

- ▶ Fujitsu's campus in Sunnyvale, CA



UTC POWER FUEL CELL SYSTEM, COCA-COLA ENTERPRISES  
ELMSFORD, NY

COURTESY OF FUEL CELL AND HYDROGEN ENERGY ASSOCIATION

**"THE FUEL CELL SYSTEMS AT OUR ELMSFORD FACILITY WILL HELP US FURTHER OUR ENVIRONMENTAL COMMITMENT TO OUR LOCAL COMMUNITIES, REDUCING OUR CARBON FOOTPRINT AND OUR USE OF THE LOCAL POWER GRID."**

Ron Lewis, Vice President of Supply Chain, Coca-Cola.



- ▶ New York Police Department
- ▶ Verizon, Garden City, NY; this is a 1.4 MW system installed in 2005 at a major call routing center/office building; funding support came from DOE and NY-SERDA
- ▶ A mixed-use apartment complex at 360 State Street, New Haven, CT.

FuelCell Energy manufactures MCFC systems. They are normally operated using natural gas, but they can also run on renewable fuels such as biogas and transportable fuels such as propane. FCE's MCFC power plants have generated over 650 million kW hours of electricity.

FCE's model 300A (250 kW, in 2003) and model DFC1500 (1 MW, in 2007) were certified as meeting CARB emission standards. In November 2010, the company announced that its 2.8 MW DFC300 power plant has been certified under CARB's 2007 distributed generation emission standards.

In 2003, FCE delivered its first commercial unit to the Kirin Brewery plant in Japan. Today its demonstration and commercial units are operating at more than 50 locations worldwide. Its product line includes systems from 300 kW to 2.8 MW. Multiple units have been combined for larger installations.<sup>[22]</sup>

- ▶ Two FCE systems totaling 1.45 MW provide about 70 percent of the electricity for a Pepperidge Farm facility in Connecticut. Funding support included \$3.5 million from the Connecticut Clean Energy Fund (CCEF) and \$500,000 from the DoD Climate Change Rebate Project.
- ▶ Four 300 kW co-generation fuel cell units provide power and heat for the Sierra Nevada brewery in Chico, CA; these units were installed in 2005. Funding for this system included \$2.4 million from the California Self Generation Incentive Program (SGIP) and \$1 million from the DoD Climate Change Rebate Project.
- ▶ Two 300 kW fuel cells provide 100 percent of the base load power at the Gills Onions processing facility in Oxnard, CA. Installed in 2009, the fuel cell system uses biogas produced from the plant's onion waste. Funding sources included California's SGIP, the California Energy Commission, and the federal investment tax credit.

Fuel cells are providing power, heat, and hot water at Starwood hotels in New York, New Jersey, and California. The total power produced by the units at these sites is 2.75 MW. Funding sup-

port came from the DoD Climate Change Rebate Project, NY-SERDA, and California's SGIP.

In July 2010, FCE announced the sale of a DFC300 to be installed at the frozen food processing facility of Carla's Pasta in South Windsor, CT. The purchaser and installer is LOGANEnergy. Fuel cell byproduct heat will be used for facility heating and hot water. The purchase was partially funded by a CCEF grant.

In March 2010, the National Assembly of the Republic of Korea adopted a Renewable Portfolio Standard as a centerpiece of the Sustainable Energy System, which requires 4 percent clean energy generation by 2015 and 10 percent by 2022. Fuel cells operating on natural gas and biogas were explicitly included in the mandated mix of ultra-clean and renewable energy. As a result of this policy, FCE has received stationary fuel cell system orders totaling tens of megawatts.



CE FUELCELL SYSTEM, PEPPERIDGE FARM BAKERY,  
BLOOMFIELD, CT  
COURTESY OF FUEL CELL AND HYDROGEN ENERGY ASSOCIATION

Bloom Energy produces systems that utilize solid oxide fuel cell (SOFC) technology to generate power. Most of its applications are between 400 kW and 2 MW, using a modular architecture consisting of 100 kW systems. Although SOFCs can provide useful thermal output, Bloom Energy systems use the waste heat internally to boost overall electrical efficiency.

The company was founded in 2001, with roots in the National Aeronautics and Space Administration (NASA) Mars space program. It announced the Bloom Energy Server in February

2010, in conjunction with several large companies that have used Bloom Energy systems since 2008 to generate power for their buildings. As of July 2011, the company has over 15 MW of fuel cell systems deployed. A Bloom Energy representative stated that these systems have operated with better than 99.5 percent availability and produced more than 85 million kW hours of electricity. Bloom Energy systems operate using natural gas or biogas. Customers include the following:<sup>[23]</sup>

- ❶ Google, with a 400 kW system on its main campus in Mountain View, CA
- ❶ e-Bay, which has a 500 kW installation on its campus in San Jose, CA
- ❶ Cox Communications, with a 400 kW system installed in January 2010 at a television station in Oakland, CA
- ❶ Safeway, which is using 200 kW of fuel cell power at a new 60,000-square-foot retail store in Santa Cruz, CA
- ❶ Walmart, with a 400 kW system at each of two southern California locations
- ❶ Cypress Semiconductor, with a 300 kW system at its campus in San Jose, CA
- ❶ Staples, with a 300 kW installation at its distribution center in Ontario, CA
- ❶ The Coca-Cola Company, which has five 100 kW fuel cell systems fueled by biogas at its Odwalla juice packaging plant in Dinuba, CA
- ❶ FedEx's hub in Oakland, CA, with a 500 kW installation
- ❶ The California Institute of Technology, which has Bloom Energy fuel cell systems totaling 2 MW installed and operational on its campus in Pasadena, CA
- ❶ Kaiser Permanente, which will have 4 MW of fuel cells deployed over seven facilities in California
- ❶ AT&T, which will be installing fuel cells totaling 7.5 MW at 11 facilities.

Customers around the world are using large (100 kW and larger) stationary fuel cell power systems. As indicated above, these customers represent a variety of markets. In choosing fuel cells, customer considerations include an assured supply of electricity, energy cost savings, and reduced environmental

impact. Supermarkets, for example, are concerned about the potential for spoilage in the event of a grid outage. In addition, energy costs are a significant portion of their operating budgets, and maintaining an image of environmental responsibility is important. Some supermarket chains, as well as other customers, seem to be moving past the early adopter stage of fuel cell technology.



UTC POWER FUEL CELL SYSTEM, WHOLE FOODS MARKET, GLASTONBURY, CT



FCE FUEL CELL SYSTEM, GILLS ONIONS, OXNARD, CA  
COURTESY OF FUEL CELL AND HYDROGEN ENERGY ASSOCIATION

Stationary fuel cell power systems much smaller than 100 kW are also being developed, and there are indications of early commercial activity. ClearEdge Power is producing high temperature proton exchange membrane fuel cells for light commercial and residential use. Its ClearEdge5 micro-CHP system provides 5 kW of electricity and 5.8 kW of heat. The company has shipped

more than 100 units to customers in California since beginning production in 2010. Systems are also installed in the greater Portland, OR, area. Current light commercial markets include multi-family housing, schools, supermarkets, and restaurants. ClearEdge Power was recently awarded a \$2.8 million grant from the DOE to support installation of 38 fuel cells for 10 commercial customers. DOE's Pacific Northwest National Laboratory will monitor the systems and measure performance.

## ► CHARACTERISTICS OF DoD MARKET

The DoD market for distributed power generation is influenced by factors and considerations addressed in Chapters 1 and 2 of this report, particularly the sections “Energy Directives and Goals” and “Beyond Demonstration: The Future of Fuel Cells in DoD.” These factors include directives to reduce energy intensity and risks associated with dependence on a vulnerable electricity grid. DoD installations require energy sources and systems that are economically competitive, secure, efficient, reliable, and environmentally friendly.

Nearly a quarter of DoD's energy consumption is accounted for by its buildings and facilities. DoD occupies more than 500,000 buildings at more than 5,000 sites.<sup>[24]</sup> The department makes substantial investments in new facilities as well as major renovations of existing facilities. For such projects, DoD relies on design, architect/engineer (A/E), and construction companies. Projects are planned and managed by organizations such

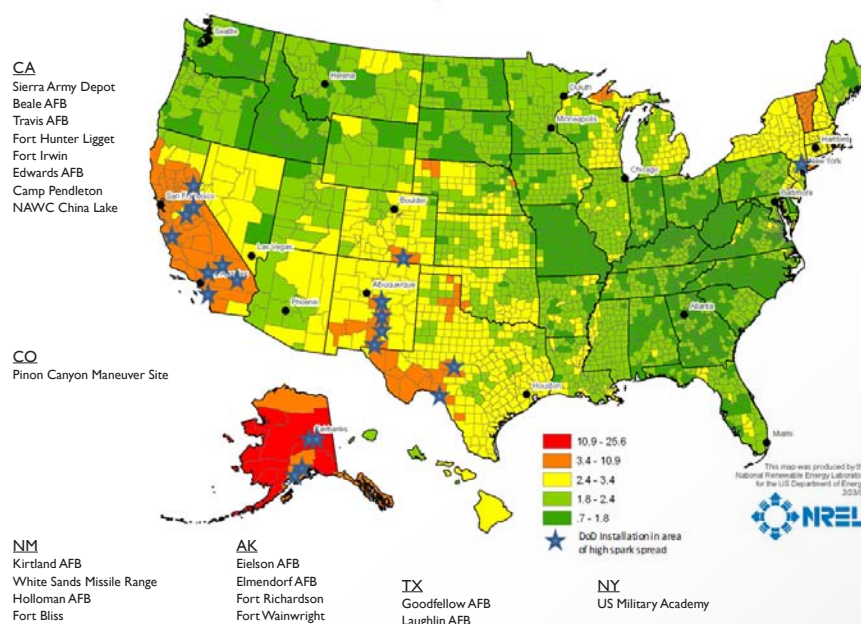
as the Army Corps of Engineers and the Naval Facilities Engineering Command. These new facilities and renovations afford opportunities to produce distributed stationary power by fuel cell systems.

DoD has numerous facilities for which fuel cell systems could be financially attractive and contribute to meeting regulatory and executive order requirements. Characteristics of such facilities include

- a large average year-round power demand (hundreds of kW), accompanied by a requirement for heat and/or cooling;
- high electric power costs and low natural gas costs (natural gas is a commonly used fuel for stationary power fuel cell systems);
- a mission-critical need for uninterruptible power;
- availability of pipeline natural gas;
- availability of waste products that could be used as a fuel source;
- a location with air quality concerns; and
- sufficient space to install a fuel cell system.

The price of electricity, relative to the price of natural gas, is an important consideration. In locations with high electricity

Figure 3-1 Ratio of Electricity to Natural Gas Rates for Commercial Use by County, 2007





and low natural gas rates, it is more likely that fuel cell systems can reduce overall energy costs. Figure 3-1 depicts the ratio of electricity to natural gas rates for all 50 states and the District of Columbia; many DoD facilities are located in states with high ratios.

The following are other important factors that amplify the merits of fuel cell power for DoD installations:

- ❶ **A requirement for both heat and electricity.** Distributed stationary power fuel cells can significantly improve overall energy system efficiency when the heat they generate is used to satisfy a facility's heating requirements. The facility's required energy can be cut by half or more when compared with using electricity from the grid and conventional means for producing steam, hot water, and/or space heating, such as boilers fueled by oil or natural gas. Total emissions can also be significantly reduced. DoD has many facilities that can benefit from combined heat and power systems.
- ❶ **Mission-critical operations.** The Defense Science Board Task Force report on DoD Energy Strategy highlighted the risk associated with over-reliance on the national electrical grid. Secure and reliable energy is most critical at mission-sensitive and high-risk installations. This consideration is particularly relevant at facilities hosting joint DoD and Homeland Security missions. In recent years, DoD's mission has expanded to include terrorism response and disaster recovery. If an attack or natural disaster occurs, an installation would provide critical value by serving as a base of operations for relief and rescue, acting as a central command to coordinate the work of other deployed national resources, and being a source of skilled personnel to provide rescue, recovery, medical, and other emergency services for survivors.<sup>[25]</sup> Command, control, communications, computers, intelligence, surveillance, and reconnaissance (C4ISR) and strategic deterrence missions are contributing to increased tactical and strategic criticality of many installations.
- ❶ **DoD initiatives to promote "net zero" energy use, water use, and waste production.** In April 2011, the Army announced pilot installations for net zero goals. For example, the goal of a net zero energy installation is to produce as much energy on site at it uses, over the course of a year. Six such sites are in the Army's pilot program. Similarly, six Army bases have been selected for the net zero waste pilot program. More installations will be selected for these initiatives during the next few years. They should provide significant opportunities for fuel cell systems.

**"THE ARMY'S VISION IS TO APPROPRIATELY MANAGE OUR NATURAL RESOURCES WITH A GOAL OF NET ZERO INSTALLATIONS. . . NOT ONLY ON A NET ZERO ENERGY BASIS, BUT NET ZERO WATER AND WASTE AS WELL."**

Office of the Assistant Secretary of the Army  
(Installations, Energy and Environment).

## ▶ VALUE PROPOSITION FOR DoD BENEFITS

Fuel cell systems for distributed stationary power production could help achieve multiple benefits for DoD. Among them are the following:

- ❶ Lower energy-related life-cycle costs, due to improved total energy system efficiency and replacement of high-cost energy with a lower cost alternative.
- ❶ Reduced system-wide and point source emissions of pollutants, including GHGs.
- ❶ An assured supply of critical electric power in the event of an electrical grid outage or other emergency. Distributed stationary power provided by fuel cells allows for the "islanding" of mission-critical installations.
- ❶ Department and military service compliance with legislative requirements, executive orders, and directives. Mandates affecting DoD relate to energy use efficiency, reduced petroleum use, and lower environmental emissions. Energy standards and targets—such as those mandated for federal agency buildings—that can be achieved by more efficient energy use should result in more serious consideration of combined heat and power systems, including those with fuel cells. (See the Chapter 1 section on "Energy Directives and Goals.")
- ❶ A positive response to the challenges and recommendations articulated in the 2008 report by the Defense Science Board Task Force on DoD Energy Strategy.
- ❶ Meeting the goals and targets specified in DoD's SSPP.
- ❶ Improving fuel cell system cost, performance, and durability, leading to further adoption of fuel cells for meeting war-fighter operational requirements.

Fuel cell systems for providing distributed stationary power commonly use natural gas, which is generally accessible at DoD installations and relatively clean. Landfill gas and wastewater treatment facility digester gas are also potential fuel sources for large systems. Because such systems include the equipment for reforming readily available input fuels, they require no investment in or construction of a separate hydrogen infrastructure.

A growing body of operational experience confirms the merits of selecting fuel cell systems for distributed power generation. DoD's facility and emergency operational needs are well matched to many commercial customer profiles and requirements for generating on-site power. An additional consideration is that large fuel cell farms could support DoD installations while concurrently supplying private-sector power requirements and thermal energy for district heating or cooling circuits.

## ISSUES AND RISKS

Fuel cell systems are expensive. The Chapter 2 section "Beyond Demonstration: The Future of Fuel Cells in DoD" addresses this and other issues relevant to DoD's future acquisition of fuel cells for multiple applications, including distributed stationary power.

Many DoD installations contract for grid electricity at low rates. As conventional electricity costs rise, particularly relative to the cost for fuels such as natural gas, the life-cycle benefits of fuel cells increase and the fuel cell value proposition improves.

Even though a growing number of fuel cell systems are providing distributed stationary power, operating experience with them is still relatively limited. Thus there are risks associated with service life, durability, and unscheduled maintenance.

Fuel cell systems producing on-site power must be monitored and maintained by an internal trained workforce or by contract. When electricity is purchased from the grid, maintaining the infrastructure for power generation, transmission, and distribution is not DoD's responsibility.

## ► RECOMMENDATIONS

The following were considerations in developing this section's recommendations:

- The recent growth in commercial sales of stationary power fuel cell systems ("DoD Fuel Cell Activities" and "Other Fuel Cell Activities" in this chapter)

- Mandated energy-related targets and goals to be met by DoD ("Energy Directives and Goals," Chapter 1)
- Concerns within DoD regarding the reliability and vulnerability of the electric power grid
- The number of DoD installations and facilities at which on-site distributed power generation, particularly co-generation of heat and power, could be competitive ("Characteristics of DoD Market," in this chapter)
- The merits of fuel cell systems compared with alternatives for distributed power production
- The large and increasing number of DoD installations and facilities with mission-critical requirements for assured electricity ("Characteristics of DoD Market," in this chapter)
- Evidence of a positive value proposition for fuel cell systems, particularly when government incentives are applied
- Customer satisfaction with fuel cell systems currently being used for distributed power generation
- The relatively immature, untested contracting models for acquiring electric power generated on site, compared with purchasing electricity from a centralized electric utility.

Recognizing the potential benefits of fuel cells for distributed power generation, and consistent with DoD's commitment to be an early adopter of technologies having public benefits, the department should do the following:

- Continue to monitor closely, evaluate, and analyze the fuel cell stationary power systems that are operational at both government and private-sector sites. This should be done in partnership with DOE and in collaboration with private-sector fuel cell providers and customers.
- Continue to support development and demonstration of fuel cell systems designed for on-site power production. Objectives of such activities include improving fuel cell performance, enhancing durability, and reducing costs.
- Support building and operation of systems that integrate multiple fuel cell and hydrogen technologies to demonstrate and enhance their long-term potential. An example would be to use a molten carbonate fuel cell system to produce both electricity and hydrogen, with dispensing of hydrogen into vehicles. Integrating stationary and transportation applications can produce greater overall system efficiencies.

- ❶ Consider and analyze fuel cell systems for meeting electric power, heating, and cooling demands whenever designing any new facility or major renovations of an existing facility. Using parameters of interest—such as life-cycle costs, energy efficiency targets in executive orders and other directives, and assured power needs in an emergency—perform a comparative analysis of options.
  - ❶ Incorporate into all A/E contracts for new DoD facilities and major renovations of existing facilities a requirement that fuel cell systems be among the options analyzed for providing electric power.
  - ❶ Ensure that procurement specifications for energy services and electric power promote consideration of fuel cell systems. Solicitations should require respondents to consider fuel cells.
  - ❶ Assess the possible business models for and potential benefits of third-party financing of distributed power production systems, to ascertain whether fuel cells could be financially more attractive for DoD users.
  - ❶ Give priority to fuel cell systems that are manufactured and assembled in the United States. Other countries are making significant government investments to help their industries become the world's major suppliers of fuel cell technologies and equipment.
  - ❶ Leverage private-sector activities by conforming DoD designs and specifications for on-site power production to those for private-sector requirements.
- DoD should develop models for energy services and power purchase agreements that make it easier to acquire fuel cell and other emerging power production technologies. The team that develops such models should include officials representing installations, energy, contracting, and legal organizations within the department. Input should be sought from parties outside DoD who have a stake in the outcome, including electric power providers, independent third-party financing interests, and the fuel cell industry. Such an initiative should also be cognizant of and informed by other DoD activities focused on improving energy efficiency and reducing the risks associated with electric grid vulnerability. They include the Smart Power Infrastructure Demonstration for Energy Reliability and Security (SPIDERS), and case studies to more specifically determine the vulnerability of electricity supply at selected sites.
- These recommendations are particularly important for officials with responsibility for
- ❶ planning, budgeting for, and managing DoD installations;
  - ❶ procuring electric power to meet the base load and emergency demands of DoD installations; and
  - ❶ complying with energy-related mandates and directives.

# CHAPTER 4

## MATERIAL HANDLING & GROUND SUPPORT EQUIPMENT

### ► RATIONALE FOR FUEL CELLS

DoD manages one of the largest distribution enterprises in the world. DLA is responsible for the second-largest warehouse operation in the United States. DoD's activities require it to own and operate thousands of vehicles designed to move materials, equipment, and supplies. These vehicles, such as forklifts, are typically powered by batteries or fueled by propane. Using MHE powered by fuel cells could reduce life-cycle costs, improve productivity, and reduce emissions.

A variety of GSE is used at DoD sites. Such equipment includes aircraft tow tractors, baggage carts, cargo tractors, maintenance carts, and high-lift service trucks. Petroleum fuels are generally used in these vehicles. Powering ground support equipment with fuel cells could reduce emissions, noise, and petroleum consumption while increasing energy efficiency.

### ► DoD FUEL CELL ACTIVITIES

Within DoD, DLA has been a leader in supporting initiatives to improve the productivity of materials distribution operations. DLA has teamed with DOE and the military services<sup>[26]</sup> to launch proton exchange membrane (PEM) fuel cell pilot projects at three DLA Defense Distribution warehouses and a Department of the Army installation. These projects are intended to assist DoD in meeting its environmental and energy security goals while creating early market opportunities for hydrogen fuel cell technologies.<sup>[27]</sup>

- **DLA Distribution Susquehanna, PA.** Forty fuel cell forklifts commenced operation in February 2009; 20 existing forklifts were retrofitted and 20 new fuel cell forklifts were acquired. East Penn/Nuvera and Plug Power each provided fuel cells for 20 forklifts. Liquid hydrogen fuel is supplied by Air Products; two indoor hydrogen dispensing systems are used. Operational and cost data have been collected and analyzed. In December 2010, an additional 15 Nuvera PowerEdge fuel cell units were delivered to DLA Distribution Susquehanna and installed in forklifts; these were funded by DOE.
- **DLA Distribution Warner Robins, GA.** Twenty new forklifts with Hydrogenics fuel cells began operation in January 2010. During its first year of operation, this project demonstrated small-scale hydrogen production by steam reforming of natural gas. Hydrogen is delivered by mobile refuelers to dispensing locations. Hydrogen production and delivery is performed by Air Products.
- **DLA Distribution San Joaquin, CA.** Twenty new fuel cell forklifts will replace 20 propane forklifts. Hydrogen will be produced

on site by water electrolysis. The project is expected to be operational in 2011.

- **Joint Base Lewis-McChord, WA.** Nineteen new forklifts are being fitted with Plug Power fuel cells; the hydrogen fuel system, involving production from the installation's wastewater treatment plant digester gas, is a joint product of the Gas Technology Institute and Air Products. The fuel cell forklifts are expected to begin operation in 2011.



MHE POWERED BY FUEL CELLS, DLA DISTRIBUTION  
SUSQUEHANNA, PA  
COURTESY OF DEFENSE LOGISTICS AGENCY

During 2 years through December 2010, the 55 fuel cell forklifts at Susquehanna and the 20 at Warner Robins were collectively operated for about 150,000 hours. More than 31,000 refuelings have been safely conducted at the two sites, with more than 18,000 kilograms of hydrogen dispensed. During 2011, DLA considered a transition from the original R&D pilot project to a longer term project at Susquehanna. A decision was made to not continue the use of fuel cell forklifts at Susquehanna and Warner Robins after completing the pilot demonstrations.

Extended-range fuel cell utility vehicles are also being demonstrated with DLA support. The purpose is to assess alternative methods for hydrogen storage. A Toro Workman fuel cell vehicle designed by ATK is being operated at Susquehanna. A Columbia ParCar vehicle, adapted for fuel cells by the Center for Transportation and the Environment (CTE), is being demonstrated at Warner Robins. ATK and CTE have also been



awarded contracts to design yard tractors powered by fuel cells.

The Air Force Advanced Power Technology Office (APTO) supported demonstrations of fuel cell MHE/GSE. APTO responsibilities have been assumed by the AFRL. The AFRL is partnering with the Hawaii Center for Advanced Transportation Technologies to demonstrate and validate fuel-efficient technologies, including fuel cells for powering Air Force ground vehicle fleets and support equipment. Included among test and evaluation projects at Joint Base Pearl Harbor-Hickam are a hybrid aircraft tow vehicle powered by a 65 kW Hydrogenics fuel cell and a flight line maintenance support vehicle with a 12 kW Hydrogenics fuel cell auxiliary power unit. A diesel floodlight set (light cart) at Hickam was modified to use a fuel cell with metal hydride storage technology; the cart is undergoing a 1-year evaluation. Two projects currently under development are a fuel cell powered R-12 refueler and a fuel cell hybrid flight line sweeper.

With funding from the Army Tank Automotive Research, Development and Engineering Center (TARDEC), 41 fuel cell class 3 forklifts were demonstrated at Sysco Corporation distribution centers in Michigan. Forklifts manufactured by the Raymond Corp. were operated at Sysco's Grand Rapids, MI, facility, and machines from Crown Equipment were used for operations at Canton, MI.

## ▶ OTHER FUEL CELL ACTIVITIES

Recently there has been significant growth in the use of fuel cells to power MHE, primarily forklifts. The American Reinvestment and Recovery Act (ARRA) provided nearly \$10 million to support deployment of fuel cell-powered forklifts and pallet trucks.<sup>[28]</sup>

- ▶ **Sysco's new distribution center in Houston, TX:** 105 Plug Power GenDrive PEM fuel cells; center opened in June 2010; hydrogen is supplied by Air Products; \$1.2 million DOE support, \$3.2 million total.
- ▶ **FedEx service center in Springfield, MO:** Retrofitting 35 forklifts with Plug Power GenDrive systems; hydrogen is supplied by Air Products; project includes evaluation and assessments; power output is 10–12 kW per unit; \$1.3 million DOE support, \$2.9 million total.
- ▶ **GENCO Supply Chain Solutions, at five distribution centers in South Carolina, Pennsylvania, Maryland, and North Carolina:** 357 Plug Power GenDrive fuel cells; hydrogen is supplied by Air

Products and Linde; fuel cell units are being deployed, for example, at a Kimberly-Clark distribution center operated by GENCO in Graniteville, SC; a Wegmans distribution warehouse in Pottsville, PA (also supported by a \$1 million grant from the Pennsylvania Energy Development Authority); and a Whole Foods distribution center in Landover, MD; \$6.1 million DOE support, \$12.2 million total.

- ▶ **H.E. Butt Groceries in San Antonio, TX:** 14 Nuvera PowerEdge PEM fuel cell systems for forklifts, and a Nuvera PowerTap hydrogen generator; objectives include validating life-cycle cost projections, productivity gains, and environmental benefits; \$1.1 million DOE support, \$3.1 million total.

**"HYDROGEN FUEL CELLS RUN LONGER, DON'T LOSE POWER AS THEY OPERATE AND ARE REFUELED MORE QUICKLY THAN BATTERIES."**

Jim Denges, CEO, Central Grocers.

Other companies are also using equipment powered by fuel cells for their material handling requirements.<sup>[29]</sup> They include:

- ▶ **Central Grocers, at its new distribution center in Joliet, IL:** More than 200 forklifts are powered by Plug Power GenDrive fuel cells; hydrogen is supplied by Air Products. The company estimates it will save \$1.5 million over 10 years.
- ▶ **Nestlé Waters:** Has converted the lift trucks at its Dallas, TX, bottling facility from propane to fuel cell power; 32 Plug Power GenDrive hydrogen fuel cells; hydrogen is supplied by Air Products.
- ▶ **Nissan North America:** Purchasing direct methanol fuel cells (DMFC) from Oorja Protonics for 60 forklifts that transport vehicle parts in its Smyrna, TN, assembly plant; decision followed an 18-month trial; 4.5 kW fuel cells; Oorja is announcing more deals.
- ▶ **Bridgestone-Firestone:** Using fuel cells for 43 forklifts at its facility in Aiken, SC; Plug Power fuel cells have replaced batteries in what is now an all-hydrogen fleet.
- ▶ **East Penn Manufacturing Company:** Converted all 10 lift trucks at its Tipton, PA, distribution center to fuel cell power using a hybrid battery/fuel cell power pack developed in partnership with Nuvera.



MHE POWERED BY PLUG POWER FUEL CELLS, NESTLÉ WATERS  
BOTTLING FACILITY, DALLAS, TX  
COURTESY OF FUEL CELL AND HYDROGEN ENERGY ASSOCIATION

A joint venture between DOE's National Renewable Energy Laboratory (NREL) and Oorja Protonics, to deploy and demonstrate methanol fuel cell powered MHE, was announced in February 2011. The fuel cells will use renewable bio-methanol, an organically derived fuel made from crude glycerin, a byproduct of vegetable oil and animal fat processing. The project involves using 75 DMFC power packs to power pallet jacks at warehouses operated by Unified Grocers (Stockton and Commerce, CA), Earp Distribution (Kansas City, KS), and Testa Produce (Chicago, IL). Oorja will cover \$1.2 million of the project costs, and NREL the remaining \$900,000. NREL will collect and analyze project data and provide a third-party assessment of fuel cell performance.<sup>[30]</sup>

NREL is providing extensive data collection and analysis for fuel cell MHE projects supported by both DLA and ARRA. Results are included in NREL's consolidated data products and reports.

**"WE'VE SEEN HOW FUEL CELLS CAN IMPROVE EFFICIENCY IN OUR DISTRIBUTION CENTERS WHILE ENABLING US TO BE MORE RESPONSIBLE GLOBAL CITIZENS."**

Johnnie Dobbs, Executive Vice President of Logistics and Supply Chain, Walmart.

## ► CHARACTERISTICS OF DoD MARKET

Nearly all of the thousands of DoD sites have operations that require MHE/GSE. In total, DoD's equipment stocks include tens of thousands of pieces of MHE/GSE. The energy required for the non-tactical portion of this equipment is counted in the consumption attributed to buildings and facilities (see Chapter 1 section "DoD Energy Use"). Electricity, petroleum products, natural gas, and propane are the primary fuels that power non-tactical MHE/GSE, and logistics fuel (JP-8) is used for tactical MHE/GSE. Non-tactical equipment has a higher potential for using fuel cell power in the near term; the MHE/GSE application discussed in this paper addresses non-tactical uses only.

MHE includes

all self-propelled equipment normally used in storage and handling operations in and around warehouses, shipyards, industrial plants, airfields, magazines, depots, stocks, terminals, and aboard ships. It includes but is not limited to warehouse tractors, forklift trucks, platform trucks, pallet trucks, straddle carrying trucks, 463L aircraft loaders, afloat and ashore warehouse industrial cranes, shipboard manlifts, and shipboard scissor platforms. It also includes nonpowered shipboard pallet trucks.<sup>[31]</sup>

GSE refers to equipment that supports aircraft operations, such as aircraft towing and servicing vehicles. For purposes of this document, GSE also includes all vehicles used aboard a military base or installation to support operations, other than on-road cars and trucks.

In 2007, DLA's equipment stocks included 5,340 pieces of MHE, with more than 4,000 forklifts.<sup>[32]</sup> Approximately half of these forklifts were powered by batteries. The others were fueled primarily by propane. Forklifts using diesel fuel are also used in many locations. A representative of the Naval Supply Systems Command advised that the Navy owns approximately 10,000 pieces of MHE, which are located throughout the Navy's facilities and ships. Although DoD's MHE/GSE inventory is not expected to increase, its replacement market is significant. DoD replaces about 10 percent of its forklifts each year.

Most DoD sites have either only a few pieces of MHE/GSE or widely dispersed MHE/GSE, with only a few items positioned at any particular point. Throughout the DoD complex, likely fewer than a hundred installations have more than 25 pieces of MHE/GSE located in close proximity, such as at DLA Distribution Susquehanna.

DoD organizations such as DLA and the U.S. Army Tank-Automotive and Armaments Command purchase MHE/GSE based on specifications that include size, performance requirements, power requirements, emissions, and noise. Capital purchase decisions for DLA's MHE are made at DLA headquarters, rather than at distribution centers and depots. Equipment purchasers consider depot needs, the age of existing equipment, and budget. Installation managers provide input to decisions about MHE power sources, such as whether to buy battery- or propane-powered forklifts. The decisions depend on equipment class and factors specific to the equipment location, such as their required lifting capability and the availability of battery charging infrastructure. With direction from the DoD customer, equipment manufacturers select the specific power and other subsystems that, when integrated, result in a product that meets specifications. Major MHE suppliers for DoD include Crown Equipment Corporation, Hyster, Yale Materials Handling Corporation, Raymond, Clark, and TCM.

Hydrogen is required for the PEM fuel cells used in MHE/GSE; however, very few DoD sites have a hydrogen infrastructure. Therefore, the availability and cost of hydrogen must be considered when determining whether to use fuel cell MHE/GSE. Hydrogen can be reformed from natural gas, which is available at DoD installations, and from waste gas generated at facilities such as wastewater treatment plants. It can also be produced by water electrolysis, or delivered from an off-site production plant.

The DoD market for MHE/GSE powered by fuel cells is influenced by factors and considerations addressed in Chapters 1

and 2, particularly the sections "Energy Directives and Goals" and "Beyond Demonstration: The Future of Fuel Cells in DoD." These factors include directives to improve energy efficiency and mandates to reduce GHG emissions.

## ▶ VALUE PROPOSITION FOR DoD BENEFITS

Some analyses have identified potential advantages for MHE powered by fuel cells. For example, Battelle's assessment of the market opportunity for fuel cells at the DLA concluded that PEM fuel cell-powered forklifts offer life-cycle cost advantages over battery- and propane-powered forklifts in two shift operations.<sup>[33]</sup> An analysis by the National Fuel Cell Research Center concluded that converting to fuel cell MHE would have multiple benefits for California residents.<sup>[34]</sup> Although life-cycle cost calculations and comparisons depend on a variety of circumstances and operating conditions, some private-sector forklift customers are choosing to use MHE powered by fuel cells ("Other Fuel Cell Activities" section of this chapter). DoD managers have several reasons to consider fuel cells:

- ▶ Increased productivity
  - Less time to refuel with hydrogen than to change out batteries.
  - Reduced maintenance requirements. Data from the first two DLA fuel cell MHE pilot projects indicate lower maintenance costs for fuel cell equipment operation.
  - Sustained lift capability during a work shift. Battery forklifts sometimes exhibit reduced voltage output as their state of charge falls.
  - Fewer forklifts needed to accomplish the mission. Reducing the number of forklifts in the fleet can be considered in situations where battery-powered forklift operators change machines when the battery is depleted rather than waiting for a battery replacement on the same machine.
- ▶ Zero emissions and quiet operation.
- ▶ Reduced space requirements for battery changing, charging, and storage.

- Assistance to installation commanders in complying with directives to conserve energy, reduce petroleum use, and reduce emissions.
- Leadership in implementing new applications for hydrogen and fuel cells, and achieving public benefits by switching to new energy technologies.

Increased fuel cell sales should lead to lower unit costs and can provide opportunities for leveraging DoD's MHE requirements with matching needs of other MHE customers.

NREL is working on a fuel cell MHE value proposition analysis, which is expected to be completed in 2011. The results of projects funded by DoD and ARRA will be included in its report.

## ISSUES AND RISKS

Fuel cells cost more than the batteries and internal combustion engines that currently provide power for most MHE/GSE. The section "Beyond Demonstration: The Future of Fuel Cells in DoD" in Chapter 2 addresses this and other issues relevant to DoD's acquisition of fuel cells for multiple applications, including MHE/GSE.

Analyses of current demonstration projects suggest that DoD's MHE operating conditions result in higher life-cycle costs for fuel cell equipment than for equipment with conventional power sources. The ideal hydrogen fuel cell forklift customer was profiled in a February 2011 presentation by representatives of Raymond, a forklift manufacturer.<sup>[35]</sup> Factors that weaken the value proposition of fuel cells for DoD forklifts include:

- *Operating tempo.* Data from the first two DLA fuel cell MHE pilot projects indicate that forklifts supporting DLA operations are generally used significantly less than two full shifts per day. Equipment requirements at distribution sites are based on having a capability to quickly meet warfighter surge demands.
- *Extra battery-powered forklifts.* Operating conditions are such that the number of battery-powered forklifts available allows operators to change machines when batteries are depleted, since the number of machines exceeds the number of operators. (Reducing the total number of forklifts could improve the fuel cell value proposition but impact the installation's surge capability.)
- *Well-established battery technology.* Previous investments in battery charging infrastructure reduce operations and maintenance costs for battery-powered forklifts. This is the situation at DLA Distribution Susquehanna.
- *Low hydrogen demand.* Low demand results in uneconomical employment of the hydrogen infrastructure investment and a large hydrogen unit cost.
- *Dispersion of equipment.* This is a factor even at sites with a large total number of pieces.

In general, the case for fuel cell equipment is more favorable when MHE options are evaluated in the context of a new facility, such as a warehouse or distribution center. The case is less favorable when fuel cell equipment is being considered for replacing MHE in an existing facility, unless all of the conventional equipment is going to be replaced. During the coming years, minimal expansion is expected at DoD facilities and operations that require forklifts. Nearly all new forklift acquisitions will replace aging equipment, and generally no more than 20 percent of the fleet at a location is replaced at one time.

Electricity prices—particularly relative to the price for fuels such as natural gas, which can be reformed to produce hydrogen—can also affect the value proposition. The operating cost for recharging batteries rises as electricity becomes more expensive. Conversely, lower electricity prices result in reduced cost for both battery recharging and producing hydrogen by electrolysis.

Even though many fuel cell forklifts are now in operation, experience with fuel cell systems is still limited compared with battery and propane forklifts. Thus there are higher risks associated with fuel cell service life, durability, and down time for unscheduled maintenance.

## RECOMMENDATIONS

Recognizing the potential benefits of fuel cells for MHE and GSE, and consistent with DoD's commitment to be an early adopter of technologies that have public benefits, the department should do the following:

- Continue to support development and demonstration of fuel cell technologies suitable for use in MHE and/or GSE. Objectives of such activities include improving fuel cell performance, enhancing durability, and reducing costs.



- Continue to support projects focusing on technologies that can reduce the cost of hydrogen delivered for fuel cell MHE/GSE and other uses.
- Monitor and participate in evaluations of fuel cell powered MHE/GSE demonstrations and commercial deployments that are sponsored by both government and the private sector.
- Assess the possible business models for and potential benefits of third-party financing of MHE/GSE, to ascertain whether fuel cells could be financially more attractive for DoD users.

As with past and ongoing DoD demonstration projects, fuel cell equipment planning and solicitation activities must address both the fuel cell MHE/GSE and related hydrogen fuel requirements. Managers should devote attention to matching hydrogen supply and total demand. This suggests that opportunities should be sought to combine the hydrogen requirements of both DoD and other users, and to supply multiple items of hydrogen-using equipment at a single location. Facilities in states

that promote investment in hydrogen infrastructure (such as California, Connecticut, South Carolina, and Hawaii) are more likely to provide the right conditions for successful demonstration projects.

During the next few years, DoD's solicitations for MHE and GSE could invite, but not require, bidders to consider and propose fuel cell options. Bidders proposing a fuel cell option would also have to address the issue of fuel supply.

Given the factors discussed under "Beyond Demonstration: The Future of Fuel Cells in DoD" in Chapter 2 and "Value Proposition for DoD" in this chapter, additional time and development progress are needed to ensure a positive value proposition for DoD investments in fuel cell-powered MHE/GSE. Ongoing government-supported activities and private-sector operations using fuel cell equipment will produce valuable knowledge and increased experience. Progress in reducing the cost of fuel cells and hydrogen will lay the groundwork for future mainstream acquisition of fuel cell MHE/GSE by DoD's vehicle fleet managers and procurement officials.

# CHAPTER 5

## BACKUP POWER

### ► RATIONALE FOR FUEL CELLS

For many operations and in many circumstances, guaranteed electrical power is critical; a disruption of power can result in significant economic losses or failure to accomplish mission requirements. Two examples requiring continuous high-quality power are telecommunications (both private-sector and government) and credit card processing. Fuel cells can provide backup power efficiently, reliably, at lower cost, and with minimal noise, reduced emissions, and less maintenance.

The Defense Science Board Task Force on DoD Energy Strategy, in its report issued in early 2008, stated that one primary energy challenge facing DoD is that military installations “are almost completely dependent on a fragile and vulnerable commercial power grid, placing critical military and homeland defense missions at unacceptable risk of extended outage.”<sup>[36]</sup>

### ► DoD FUEL CELL ACTIVITIES

In FY08, federal interagency agreements helped deploy fuel cells for backup power at multiple locations. DoD sites with such projects are Fort Jackson, SC, Los Alamitos Joint Forces Training Base, CA, and Marine Corps Logistics Base (MCLB) Barstow, CA. The Army’s CERL, DOE, and South Carolina’s Advanced Technology Institute partnered to deploy 10 Plug Power fuel cell backup power units for three mission-critical functions at Fort Jackson: the telecommunications center, an energy monitoring and control facility, and an emergency services center. The fuel cells were installed for an 18-month demonstration period starting in September 2009. The project, which was designed to advance the goals of the DOE “market transformation” initiative, included monitoring and assessing the performance, durability, and life-cycle costs of commercially available 5 and 15 kW fuel cells. Fuel cells will provide backup power for emergency response operations at Los Alamitos using hydrogen produced on site, and at MCLB Barstow using bottled hydrogen.

The backup power fuel cells at Fort Jackson have met expectations. Officials report complete satisfaction with their performance and reliability, particularly in response to three power outages. No power interruptions have occurred for any of the critical loads backed up with these systems.

During 2008, Plug Power fuel cells were installed at New Mexico National Guard sites. A total of 20 GenCore units were tested and operated at Santa Fe and Rio Rancho. Funding came from the Army TARDEC, with technical support from CERL.



PLUG POWER FUEL CELL BACKUP POWER SYSTEM, FORT JACKSON, COLUMBIA, SC  
COURTESY OF LOGANENERGY

The load was successfully carried by fuel cells during a May 2008 utility grid outage at the aviation support facility.

In November 2009, CERL issued a Broad Agency Announcement (BAA) seeking demonstrations of fuel cell systems for backup power. The BAA’s core requirement was a turn-key package for the installation, operation, maintenance, monitoring, and removal and site restoration of domestically produced PEM fuel cells as backup power supplies. The objectives included determining the feasibility of fuel cells in backup power applications and building a database of operational performance. Fuel cell backup power units will be deployed at nine federal installations—eight DoD and one NASA. A total of 217 kW will be provided for meeting mission-critical power demands at 18 separate buildings. The NASA location is at the Ames Research Center in California. The eight DoD host sites are:

1. U.S. Army Aberdeen Proving Ground, MD
2. U.S. Army Fort Bragg, NC
3. U.S. Army Fort Hood, TX
4. Ohio National Guard
5. U.S. Army Picatinny Arsenal, NJ
6. U.S. Marine Corps Air Ground Combat Center Twenty-nine Palms, CA
7. U.S. Military Academy, West Point, NY
8. Cheyenne Mountain Air Force Base, CO.

The CERL acquisition was awarded to LOGANEnergy, which will manage the project. Fuel cell backup power systems from four manufacturers (ReliOn, Inc., Altery Systems, IdaTech, and Hydrogenics) will be installed starting in July 2011 and are expected to operate for 5 years under the demonstration program. Bottled hydrogen will be used at all but one site. Methanol will be reformed to provide the hydrogen at Twentynine Palms. DOE will fund the majority of the \$2.5 million cost-shared effort, and CERL will manage the project. Performance data for the first 2 years will be collected, analyzed, and disseminated by NREL. To facilitate an exchange of information, fuel cell users groups will be hosted by TARDEC.

The APTO funded an initiative to install fuel cells for backup power at critical Hawaii Air National Guard sites. This project is now managed by the AFRL. The objective is to demonstrate the viability of fuel cells as replacements for diesel generators. The Guard is assessing which facilities will participate in this evaluation and the duration of the backup power requirement.

With ARRA funds, a total of 20 6 kW GenSys PEM fuel cell systems will be installed and operated by Plug Power at Fort Irwin, CA, and Warner Robins AFB, GA. These units will have quick start capability with hydrogen, and are designed to operate continuously for extended periods using liquid propane gas (LPG). Project partners include CERL, which is helping to coordinate and identify loads to be supported with fuel cells. The systems will be installed in 2011. The total project cost is \$5.4 million, including \$2.7 million from DOE.

In late 2009, IdaTech's German OEM partner, b+w Electronic Systems, delivered 22 ElectraGen fuel cell systems to the U.S. Army in support of the Infrastructure Modernization program. The program supports the upgrade and modernization of enterprise enabled voice and data networks worldwide. Ten ElectraGen systems were installed in Grafenwoehr, Germany, and 12 systems have been deployed to other U.S. military sites throughout Germany.

**"BECAUSE DOD FACES SUBSTANTIAL RISKS TO ITS MISSIONS VIA GRID AND OTHER CRITICAL INFRASTRUCTURE VULNERABILITY, IT MUST FIND MEANS TO MANAGE THESE RISKS."**

Report of the Defense Science Board Task Force on DoD Energy Strategy, "More Fight – Less Fuel," February 2008.

## ▶ OTHER FUEL CELL ACTIVITIES

ARRA included more than \$18 million to deploy 1 to 10 kW fuel cell-based backup power for government sites, utility communications, telecommunications, and state and local first responders. (Projects at Fort Irwin and Warner Robins AFB are included in the "DoD Fuel Cell Activities" section of this chapter above.)

▶ Sprint Nextel is demonstrating the viability of 1 to 10 kW fuel cell systems, with 72 hours of on-site fuel storage, for backup power to communication facilities used by state and local first responders and 911 centers. The project includes PEM fuel cells from Altery and ReliOn, and hydrogen provided by Air Products. Sprint will deploy 260 new fuel cells at sites in California, Connecticut, New Jersey, and New York, and 70 retrofits of in-service fuel cells in Louisiana and Texas. A hydrogen storage solution has been identified. Life-cycle costs, performance, and operational characteristics will be benchmarked relative to incumbent technologies. Of \$24.5 million in total funding, \$7.3 million comes from DOE.<sup>[37]</sup>

▶ ReliOn is deploying about 200 fuel cells with a new refillable 72-hour fuel system at locations in eight states. AT&T and Pacific Gas and Electric are providing host sites; Air Products is supplying fuel and storage. Support is being provided for installation, fueling logistics, and operating data acquisition for fuel cells used to power voice and data communications networks under a variety of conditions. Of \$18.1 million in total funding, \$8.6 million comes from DOE.

**"THIS HYDROGEN FUEL CELL DEPLOYMENT IS THE TIP OF THE ICEBERG FOR US. . . WE ARE MAKING GREAT PROGRESS IN PURSUING ENVIRONMENTALLY SOUND ALTERNATIVE ENERGY SOLUTIONS TO POWER OUR NETWORK."**

Sarabeth Patch, Sprint Environmental Sustainability Communications Manager.

NREL is providing data collection and analysis for fuel cell backup power projects supported by DOE interagency agreements and ARRA. Results are included in NREL's con-



RELION FUEL CELL BACKUP POWER SYSTEM, SPRINT CELL  
PHONE TOWER  
COURTESY OF FUEL CELL AND HYDROGEN ENERGY ASSOCIATION

solidated data products and reports on system operation, maintenance, and performance.

Other fuel cell backup power initiatives include:

- ▶ The installation of more than 330 Altery Freedom Power Systems in southern Florida for Metro PCS. This program was announced in November 2009. The 5, 10, and 15 kW systems were installed at 140 telecommunications sites covering more than 10,000 square miles.
- ▶ Approximately 250 hydrogen fuel cells installed as backup power sources for Sprint cell sites prior to the ARRA award made to Sprint Nextel.
- ▶ IdaTech's design and manufacture of extended-run fuel cell backup power systems for telecommunications applications. IdaTech has produced more than 800 ElectraGen systems, which are installed in more than 30 countries. Many of these installations are in regions with poor electric grid quality, including Indonesia, Mexico, the Philippines, and Trinidad. The fuel commonly used in these systems is IdaTech's HydroPlus, a mixture of 62 percent methanol and 38 percent

de-ionized water. The power output of its fuel cells ranges from 500 watts to 10 kW. IdaTech notes that the cost of HydroPlus is similar to diesel, and significantly less than the cost of hydrogen; and that systems fueled by HydroPlus are more compact and lighter weight than comparable diesel generators, thereby enabling installations, for example, on rooftops.

- ▶ A project to deploy fuel cell backup power systems at 26 Federal Aviation Administration (FAA) sites. Under provisions of a 2009 interagency agreement, DOE purchased ReliOn fuel cells for this project. The fuel cells are intended to provide backup power for radio transmit-and-receive sites and air traffic control sites located across the FAA's three service centers (east, central, and west). The FAA has installed six of the systems. Before this new project, the FAA had 28 sites using ReliOn fuel cells for backup power.

## ▶ CHARACTERISTICS OF DoD MARKET

DoD requires reliable and "always-on" power for many mission-critical tasks. The risk of an electric power disruption at DoD installations is a function of multiple factors, including

- ▶ natural disasters such as hurricanes, earthquakes, and storms;
- ▶ terrorist activity, including cyber attacks, affecting electricity transmission and the distribution infrastructure;
- ▶ an accident that, for example, severs a power line or results in failure of key equipment in the power distribution system;
- ▶ an equipment failure within the power generation, transmission, and distribution system; and
- ▶ an interruption in supplies required by generating plants, such as natural gas or coal.

In DoD, numerous sites have a mission-critical or other need for continuous power. For example, DoD operates about 1,000 radio transmitter sites.<sup>[38]</sup> As indicated in the 2008 report of the Defense Science Board Task Force on DoD Energy Strategy, the potential for domestic terrorist attacks, and a homeland defense mission for DoD, have created a new role for military installations. Historically the main mission of DoD installations has been related to training and deploying forces. As mentioned in Chapter 3, however, the mission has expanded to include terrorism response and disaster recovery.<sup>[39]</sup> C4ISR and strategic deterrence missions are contributing to increased



tactical and strategic criticality at many sites. Operations with critical power needs are often located in harsh environments, including extreme heat and cold, and in areas with low electric grid reliability.

DoD currently relies primarily on diesel-fueled generators to provide assured power for its critical operations. Battery-powered backup systems are also commonly used. The Defense Science Board Task Force report concluded that current backup power for DoD requirements is inadequate in terms of size, duration, and reliability.

Recommendations have been made that DoD undertake a more thorough analysis of the risks associated with power disruptions. For example, the following recommendations from the 2008 Defense Science Board Task Force report are relevant to the discussion of backup power technologies.

- The Assistant Secretary of Defense for Homeland Defense and Americas' Security Affairs (ASD [HD&ASA]), in coordination with the Joint Staff and Office of the Deputy Under Secretary of Defense for Installations and Environment (ODUSD [I&E]), should develop a program plan to assess the risks to mission from power failure, identify mitigation options, assess their efficacy, and develop a phased investment plan to bring the risks to within acceptable limits at CONUS and OCONUS.
- The ASD (HD&ASA), in coordination with the Joint Staff and ODUSD (I&E), should complete risk assessments for critical C4ISR and strategic deterrence missions and identify the most cost effective risk mitigation options to assure mission resilience, to include efficiency to reduce the demand for on-site power, enhanced backup capability via greater on-site generator capacity, and provision of on-site alternative sources of power.

The 2010 DoD SSPP states that the department is beginning what will likely be a major effort to address the risks from potential disruptions to the commercial electric grid. It is participating in inter-agency discussions on the magnitude of the threat and investigating how to ensure that DoD has the energy needed to maintain mission-critical operations.<sup>[40]</sup> Such an analysis could indicate there are relatively few critical needs for which a short-term backup power capability, such as for 24 hours, is sufficient to address the risk. In some situations, a backup capability that can provide power for weeks or even months may be preferable. (See Chapter 3, "Distributed Stationary Power," for a discussion of systems that can provide longer term backup power.)

Pure hydrogen is generally required for operating the fuel cells typically used for backup power. Very few DoD installations have a hydrogen infrastructure. In the United States, however, hydrogen is readily available for small-scale projects from compressed gas suppliers. Refueling capability may be a consideration, depending on the period for which backup power is required. In general, fuel cell systems currently installed for backup are intended to operate continuously for at least 12 hours, and storage of the fuel needed is integral to the system. ARRA-funded projects are testing new approaches to hydrogen delivery, refueling, and storage. Hydrogen required for longer term operation can be reformed on site and on demand from methanol, propane, natural gas, or waste gas, which are or can be readily available at DoD facilities.

DoD organizations purchase backup power systems based on specifications that include size, minimum period of operation, performance requirements, power requirements, emissions, and noise.

The DoD market for fuel cell backup power is influenced by factors and considerations addressed in Chapters 1 and 2 of this report, particularly in the sections "Energy Directives and Goals" and "Beyond Demonstration: The Future of Fuel Cells in DoD." These factors include the risks associated with dependence on a vulnerable electricity grid and mandates to decrease emissions.

**"WE HAVE THE GREAT OPPORTUNITY TOGETHER TO BE EARLY ADOPTERS OF NEW ENERGY TECHNOLOGIES THAT WILL IMPROVE OUR SECURITY AND WILL ONE DAY HAVE A BROADER UTILITY TO THE NATION."**

Admiral Gary Roughead, Chief of Naval Operations, at CNO Environmental Awards Ceremony, May 28, 2009, Washington, DC.

## ▶ VALUE PROPOSITION FOR DoD BENEFITS

A Battelle analysis of FAA backup power, reported on in 2008, concluded that PEM fuel cells offer a lower life-cycle cost than batteries for applications requiring less than 5 kW with extended backup run times.<sup>[41]</sup> Battelle also reported that, compared with batteries, PEM fuel cells have lower maintenance requirements, can be monitored remotely, have longer continuous runtimes, maintain steady voltage, and are more durable in

harsh environments. A 2008 report by the National Fuel Cell Research Center states that

PEM fuel cells are a solid state backup power solution that incorporates the best attributes of combustion generators and batteries, while avoiding the weaknesses of each of those technologies. Although they have a higher first cost, PEM fuel cells offer improved system reliability, predictable performance across a broad range of climates, a reliable service life, and near zero on-site emissions.<sup>[42]</sup>

NREL has published some results on operation and performance of fuel cell backup power systems.<sup>[43]</sup> For example, it has recorded 408 successful starts of 409 attempts over a year and a half. A fuel cell backup power value proposition analysis being prepared by NREL is expected to be completed in 2011. The results of projects funded by DoD and ARRA will be included in the resulting report.

Considering these analyses and the growing body of operational experience, selecting fuel cell systems for meeting backup power requirements could bring multiple benefits for DoD. Its facilities and emergency operational needs are well matched to many commercial customer profiles and requirements for backup power. One fuel cell manufacturer indicates that, when the first cost for a fuel cell system is less than 20 percent higher than an equivalent diesel generator, the benefits of the fuel cell outweigh the additional cost. Private-sector customers of fuel cells for this application, such as Sprint,<sup>[44]</sup> report that their fuel cell systems have:

- ▶ A longer life span, resulting in fewer replacements than battery or diesel-powered systems. When fuel cell systems are employed, batteries supply only initial backup power needs. The resulting smaller battery requirements reduce the number and size of batteries requiring replacement.
- ▶ Lower maintenance requirements, requiring fewer site visits.
- ▶ Decreased GHG and other emissions.
- ▶ Better capability for remote monitoring.

Fuel cells also offer improved system energy conversion efficiency and reduced noise when compared with diesel generators. Additionally, liquid fuels such as methanol and LPG demonstrate improved fuel stability relative to diesel and offer the extended run times demanded by some DoD circumstances. DoD use of fuel cells for backup power can demonstrate its leadership in implementing new hydrogen and fuel cell applications, as well as its commitment to achieving the public benefits of new energy technologies.

## ISSUES AND RISKS

Fuel cell systems are more expensive than conventional backup power systems. Although studies such as Battelle's indicate a lower life-cycle cost for fuel cell systems, government subsidies have been a key factor in the recent growth of domestic markets for fuel cell backup power. The Chapter 2 section "Beyond Demonstration: The Future of Fuel Cells in DoD" addresses this and other issues relevant to DoD's future acquisition of fuel cells for multiple applications, including backup power.

The types of fuel cells used for backup power require hydrogen, which can be delivered by compressed gas suppliers or produced on site from another fuel source. Different fuel options each have their proponents. Systems can use propane, natural gas, or methanol, which are generally accessible at DoD installations and relatively clean. IdaTech's technology can use a mixture of methanol and water, as described in the "Other Fuel Cell Activities" section of this chapter above.

Even though there are a large number of fuel cell backup power systems, operating experience with them is still relatively limited. Thus there are risks associated with service life, durability, and unscheduled maintenance issues.

## ▶ RECOMMENDATIONS

The factors we considered in developing fuel cell backup power recommendations include:

- ▶ The recent growth in commercial sales and success of fuel cell systems for backup power ("DoD Fuel Cell Activities" and "Other Fuel Cell Activities" in this chapter)
- ▶ Concerns within DoD regarding the reliability and vulnerability of the electric power grid
- ▶ The large and increasing number of DoD installations and facilities with mission-critical requirements for assured electricity ("Characteristics of DoD Market" in this chapter)
- ▶ Evidence of a positive value proposition for fuel cell systems, particularly when government incentives are applied
- ▶ Customer satisfaction with fuel cell systems currently being used for backup power
- ▶ The lack of a mature, tested contracting model to enable efficient procurement of fuel cell backup power.



Recognizing the potential benefits of fuel cells for backup power, and consistent with DoD's commitment to be an early adopter of technologies having public benefits, the department should do the following:

- Monitor and participate in evaluations of fuel cell systems currently providing backup power at both government and private-sector locations.
- Continue to support development, demonstration, and commercial deployment of fuel cell systems suitable for backup power. Objectives of such activities include improving fuel cell performance, enhancing durability, and reducing costs, as well as investigating fuel-related innovations such as hydrogen storage technologies.
- Always consider and analyze fuel cell systems whenever seeking a capability to ensure continuous power in the event of a primary electricity supply disruption.
- Consider fuel cell systems for backup power whenever designing a new installation or major facilities renovation. Using parameters of interest—such as life-cycle costs, reliability, durability, emissions, noise levels, and run time—perform a comparative analysis of options.
- Incorporate into all A/E contracts for new DoD facilities and major renovations of existing facilities a requirement that fuel cell systems be among the options analyzed for providing backup electric power.
- Ensure that procurement specifications for backup power promote consideration of fuel cell systems. Solicitations should require respondents to consider fuel cells.
- Assess the possible business models for and potential benefits of third-party financing of backup power systems, to ascertain whether fuel cell-powered equipment could be financially more attractive for DoD users.

- Consider service contracts with third-party financing and asset ownership.

- Give priority to fuel cell systems that are manufactured and assembled in the United States. Other countries are making significant government investments to help their industries become the world's major suppliers of fuel cell technologies and equipment.

- Leverage private-sector activities by conforming DoD designs and specifications for backup power fuel cell systems to those for private-sector requirements.

DoD should develop models for procuring energy services that result in more efficient acquisition of fuel cell and other emerging power production technologies, including those for providing backup power. The team that develops such a model should include officials representing installations, energy, contracting, and legal organizations within the department. Input should be sought from parties outside DoD who have a stake in the outcome, including electric power providers, independent third-party financing interests, and the fuel cell industry. Such an initiative should also be cognizant of and informed by other DoD activities that focus on improving energy efficiency and reducing the risks associated with electric grid vulnerability. They include the SPIDERS, and case studies to more specifically determine the vulnerability of electricity supply at selected sites.

These recommendations are particularly important for officials with responsibilities for

- planning, budgeting for, and managing DoD installations;
- procuring the electric power for emergency demands of DoD installations;
- complying with energy-related mandates and directives; and
- managing information technology systems.

# CHAPTER 6

## UNMANNED VEHICLES

### ► RATIONALE FOR FUEL CELLS

*The last six years have proven, without a doubt, that unmanned systems operating in the air, on land, and in maritime domains have significantly contributed to accomplishing the Department's missions.*<sup>[45]</sup>

Unmanned vehicles—aerial, ground, and underwater—are increasingly important elements of DoD's mission capability. In this application, mission requirements, performance, and benefits are priority considerations in choosing vehicle electric power options. Many unmanned vehicles are currently powered by batteries. Fuel cells and other technologies, including solar energy systems and internal combustion engines, are also options. Among the alternatives, fuel cells have excellent capability to provide benefits critical to the success of unmanned vehicle missions. They can deliver more power per unit weight while reducing a vehicle's heat signature and noise. A fuel cell's uninterrupted power density can reduce vehicle size and extend mission endurance. Such improved capability could justify a cost premium.

### ► DoD FUEL CELL ACTIVITIES

*In response to the Warfighter demand, the Department has continued to invest aggressively in developing unmanned systems and technologies.*

—DoD FY09–34 Unmanned Systems Integrated Roadmap

In March 2008, AeroVironment (AV) announced a successful flight, in excess of 9 hours, by its Puma UAV, which was powered by a fuel cell-battery hybrid system. The flight time exceeded the Puma's previous record of more than 7 hours completed in July 2007, and the 2.5 hours achieved by the battery-only Puma. This demonstration took place under AV's contract with the AFRL for "the development of advanced energy storage and propulsion technologies for unmanned aircraft."<sup>[46]</sup> A Protonex Pulse fuel cell was used for this project. In April 2009, AV's Puma flew for more than 7 hours utilizing a Protonex ProCore UAV fuel cell system (proton exchange membrane/chemical hydride) lithium ion battery hybrid.

In March 2009, Protonex announced a \$3.3 million contract award from DoD to develop a new fuel cell system to power a small UAV capable of extended flight and a classified mission endurance.<sup>[47]</sup> This project included customizing a Protonex fuel cell platform and integrating it into an AV Puma AE (All Environment). The Puma AE is a UAV equipped with both elec-

tro-optical and infrared cameras that can operate over land or water.

In May 2009, Protonex announced a \$265,000 award from the AFRL to develop high-performance fuel cell systems capable of powering small UAVs.<sup>[48]</sup> Subsequently, Protonex integrated a miniature fuel cell system into AeroVironment's Raven UAV. It achieved a flight time of approximately 3 hours, which doubled the 1.5-hour flight of the battery-only Raven.<sup>[49]</sup>

In November 2009, the Naval Research Laboratory (NRL) Ion Tiger UAV achieved an unofficial world endurance record of 26 hours and 1 minute while carrying a 5-pound payload.<sup>[50]</sup> For this flight, the Ion Tiger was powered by a 550 watt Protonex PEM fuel cell fueled with compressed hydrogen. The Ion Tiger program is sponsored by the Office of Naval Research (ONR); the NRL-led system development team includes Protonex, the University of Hawaii, HyperComp Engineering, and Arcturus UAV. The next step for the program is to increase the fuel cell power to 1.5 kW for greater flight duration and increased payload capacity.



THE ION TIGER  
IMAGE PROVIDED COURTESY OF THE NRL

In April 2009, the Army Talon robotic UGV, built by Foster-Miller and powered by a Protonex PEM fuel cell with 200 watts of continuous power, demonstrated a threefold range increase (from 15 km to 45 km) and a twofold energy density increase over a battery-powered vehicle. The Talon uses a hybridized fuel cell-battery system and was part of the Next Generation Manufacturing Technologies Initiative funded through DLA.

In May 2009, Adaptive Materials, in partnership with the National Automotive Center, TARDEC, and DARPA, demonstrated its iRobot Scout UGV at Camp Grayling, MI. The Scout was powered by an Adaptive Materials-manufactured fuel cell-battery hybrid energy system. The 150-watt SOFC was fueled by three 8-ounce canisters of propane gas. The Scout achieved a 3.1 mph constant speed for 40 miles, with a peak power output of 600 watts. These results surpassed those of battery-only UGVs under similar conditions.<sup>[51]</sup>

In September 2010, the NRL and GM entered into a \$1.6 million cooperative agreement to evaluate a GM hydrogen-fueled fuel cell as a UUV power system. This is part of a larger Navy effort to develop and evaluate fuel cells for UUV power.

The Naval Undersea Warfare Center has been conducting R&D of SOFCs for UUVs. In January 2010, it announced plans to award a contract to Delphi Automotive Systems to develop a 30-cell SOFC system to power UUV applications.<sup>[52]</sup>

The Hawaii Natural Energy Institute's fuel cell R&D program—which is funded in part by ONR through the Hawaii Energy and Environment Technology Initiative and by DOE through the Hawaii Hydrogen Center for Development and Deployment of Distributed Energy Systems—consists of four components: fuel cell testing, fuel cell systems, fuel cell fabrication, and alternative approaches to fuel cell development.<sup>[53]</sup> The institute conducts simulations and assessments of several fuel cell applications, including UAVs, UGVs, and UUVs.

Under a DoD-funded Small Business Innovation Research program, Precision Combustion Inc. (PCI) has developed and demonstrated an autothermal reformer that can convert high-sulfur logistics fuel into a low-sulfur hydrogen-rich gas. The gaseous reformat can fuel SOFCs that could power UXV applications. PCI's Microlith catalyst technology was used as the basis for the fuel processor's reforming reactor.<sup>[54]</sup>

**“QDR INITIATIVES INCLUDE... EXPAND MANNED AND UNMANNED AIRCRAFT SYSTEMS (UASs) FOR INTELLIGENCE, SURVEILLANCE AND RECONNAISSANCE ...”**

DoD Quadrennial Defense Review Report, February 2010.

## ► OTHER FUEL CELL ACTIVITIES

*Until recently, UASs mainly supported military and security operations, but that is rapidly changing. Unmanned aircraft promise new ways to increase efficiency, save money, enhance safety and even save lives. Interest is growing in a broad range of uses such as aerial photography, surveying land and crops, monitoring forest fires and environmental conditions, and protecting borders and ports against intruders.*

—FAA Fact Sheet, Unmanned Aircraft System (UAS), December 1, 2010

In October 2009 United Technologies Research Center (UTRC) demonstrated its hydrogen/air fuel cell-powered mini-helicopter for 20 minutes with a 5 pound payload. UTRC began with a mini-helicopter previously powered by lithium ion batteries and retrofitted it with a PEM fuel cell power plant. The 1.75 kW fuel cell, which UTRC based on UTC Power's proprietary fuel cell technology, used a 4,200 psi hydrogen source.<sup>[55]</sup> UTC viewed this as a milestone in fuel cell-powered flight, because helicopters require more power for lift than fixed-wing aircraft. The mini-helicopter could conceivably be used for military or police surveillance, or as a hobby aircraft similar to battery-powered versions.

A consortium led by the Swiss Federal Institute of Technology Zurich performed the final demonstration of its muFly mini-UAV project in November 2009. The project objective was to build a fully autonomous micro-helicopter comparable in size and weight to a small bird. The muFly can be dispatched in disaster situations to search for people in collapsed buildings and investigate contaminated areas. The consortium turned to the Fraunhofer Institute's Department for Reliability and Microintegration to develop a lightweight fuel cell to power the muFly. The institute worked with the Technical University of Berlin to develop a fuel cell that weighs 30 grams and has an output of 12 watts.

The AEROPAK PEM fuel cell system was developed by Horizon Fuel Cell Technologies, a subsidiary of Singapore-based Horizon Energy Systems (HES). This system, which weighs 4.4 pounds and produces 900 Wh of energy, has provided power for various UAV tests and demonstrations.

In August 2009, BlueBird Aero Systems showcased its Boomerang, the world's first UAV powered by a commercially available fuel cell. Using the AEROPAK fuel cell, the Boomerang's maximum flight time increased from 3 to 9 hours. The Boomerang can be used for border patrol, infrastructure surveillance,

critical asset monitoring, and environmental monitoring. It is licensed for flights in Israel.<sup>[56]</sup>

An August 2010 announcement stated that Israel Aerospace Industries extended the flight endurance of the Bird Eye 650 mini-UAV using a PEM fuel cell system by HES. The 6-hour flight more than doubled the endurance of a lithium battery-powered counterpart while maintaining the same weight. The Bird Eye 650 can be used for tasks that include surveillance, reconnaissance, and escorting patrols and convoys.



THE BIRD EYE 650  
COURTESY OF FUEL CELL AND HYDROGEN ENERGY ASSOCIATION

In November 2010, HES announced that its fuel cell system helped set a new record for electric flight duration. The project effort, led by the Korean Aerospace Research Institute (KARI) and HES, retrofitted a lithium battery-powered RemoEye-006 UAV manufactured by South Korea's Uconsystem. The fuel cell UAV, named EAV-1, achieved a flight time of 5 hours, 3 hours more than the battery-powered version. The flight took place in October 2010 at KARI's flight test site at Goheung.<sup>[57]</sup> The EAV-1 can be used for intelligence, surveillance, and reconnaissance.

In November 2010, the P.I. Baranov Central Institute of Aviation Motors (CIAM) in Russia completed a several-minute test flight of its hydrogen fuel cell-powered CIAM-80 UAV. The CIAM-80 is a reconnaissance UAV that can be used in commercial applications.<sup>[58]</sup>

In December 2010, HES announced a successful flight of Elbit Systems' Skylark I-LE, a UAS used by several nations for close-range surveillance and reconnaissance. The Skylark doubled its previous flight time. The flight took place in Israel and simulated real battlefield conditions with an actual payload.<sup>[59]</sup>

## ► CHARACTERISTICS OF DoD MARKET

### CURRENT MARKET

*In today's military, unmanned systems are highly desired by combatant commanders (COCOMs) for their versatility and persistence.*

—DoD FY09–34 Unmanned Systems Integrated Roadmap

As of October 2009, DoD had more than 6,800 UAVs in its inventory.<sup>[60]</sup>

### CURRENT OPERATIONS

The DoD FY09–34 Unmanned Systems Integrated Roadmap maps current unmanned systems against Joint Capability Areas (JCAs) to determine how the systems are contributing to DoD missions. It determined that unmanned systems are already key contributors to:

- **Battlefield awareness.** Unmanned systems significantly contribute to battlefield awareness through aerial and urban intelligence, surveillance, and reconnaissance (ISR).
- **Force application.** UASs conduct offensive operations, irregular warfare, and high-value target/high-value individual missions. Talon robots are being used in theater to find and defeat improvised explosive devices (IEDs), house-borne IEDs, landmines, and other types of explosives. UAVs were a large part of the mine clearing effort during Operation Iraqi Freedom in 2003.
- **Protection.** Unmanned systems have been used in numerous relief and recovery efforts. Pacific Air Force officials used the RQ-4 Global Hawk UAV to assist in the disaster relief and recovery efforts following the March 2011 earthquake and resulting tsunami off the eastern coast of Japan.<sup>[61]</sup> The Navy contemplated sending its experimental K-Max unmanned helicopter to Japan to assist in cooling the spent fuel rods at the Fukushima Daiichi nuclear plant. The Global



Hawk was also used for disaster relief efforts following the earthquake that struck Haiti in January 2010. UUVs were used for Hurricane Katrina recovery operations in 2005. Talon robots were used in New York at Ground Zero for search and recovery efforts after September 11, 2001.

## FUTURE MARKET

*These successes, however, likely represent only a fraction of what is possible and desirable by employing unmanned systems.*

—DoD FY09-34 Unmanned Systems Integrated Roadmap

Section 141 of the John Warner National Defense Authorization Act of FY07 (NDAA 2007) required DoD to establish guidance on unmanned systems. DoD subsequently developed the FY09–34 Unmanned Systems Integrated Roadmap to assess progress toward meeting the NDAA 2007 goals. The roadmap establishes a vision and strategy for investing in unmanned systems and technologies that will continue to assist DoD in accomplishing its missions. It provides recommendations for future actions with respect to unmanned vehicles; however, it also recognizes that time and budgetary pressures could alter their implementation. It does not imply that decisions have been made or funding has been dedicated based on its projections.

The President's Budget for FY12 indicates a commitment to investing in unmanned systems. The DoD portion of the budget reinvests \$100 billion of \$178 billion in expected savings into high-priority areas.<sup>[62]</sup> The budget increases funding in ISR capabilities, which includes UAVs, to \$4.8 billion.<sup>[63]</sup>

Continued growth is expected for the Army's UAS program. The program's deputy project manager stated that the Army plans to accelerate its Gray Eagle program from two companies per year to three, which will result in 17 new systems by 2014.<sup>[64]</sup> The Army is also expanding the size and range of its overall fleet to include a family of small and vertical-takeoff-and-landing UASs.<sup>[65]</sup> Air Force Chief of Staff General Norton Schwartz has characterized the Air Force UAS program as "profoundly important"<sup>[66]</sup> and envisions its expansion. The UAV's support to ground troops "has never been more important."<sup>[67]</sup>

There are three major market segments for unmanned systems: military, civil government, and commercial. There are 100 companies, academic institutions, and government organizations developing more than 300 designs for UASs alone.<sup>[68]</sup> In

a 2011 market study, the Teal Group estimates that the UAV market will total more than \$94 billion in the next 10 years despite anticipated cuts in defense spending. The United States is predicted to account for 77 percent of the world research, development, test, and evaluation spending and 69 percent of the procurement in that time span.<sup>[69]</sup> Most of the spending and procurement will be done by military and civil government organizations, because an established domestic commercial market for UASs is still several years away.

## FUTURE OPERATIONS

Future uses for unmanned vehicles may extend well beyond their current missions. The Integrated Roadmap maps projected unmanned systems against JCAs to determine how unmanned systems can contribute to DoD missions in the future. Its conclusions indicate that future unmanned systems could be key contributors to:

- **Battlefield awareness.** Unmanned systems in all domains can significantly contribute to future battlefield awareness. Missions will include expeditionary runway evaluation, nuclear forensics, and special forces beach reconnaissance. Future applications will require longer mission endurance to conduct persistent reconnaissance and surveillance.
- **Force application.** Unmanned systems are projected to have a large presence in this JCA. Future missions for UAVs include air-to-air combat and suppression and defeat of enemy air defense. UGVs are expected to conduct missions such as non-lethal and lethal crowd control, dismounted offensive operations, and armed reconnaissance and assault operations. UUV and unmanned surface vehicle missions are projected to include mine laying as well as mine neutralization.
- **Protection.** Unmanned systems are projected to perform tasks such as firefighting, decontamination, forward operating base security, installation security, obstacle construction and breaching, vehicle and personnel search and inspection, mine clearance and neutralization, more sophisticated explosive ordnance disposal, casualty extraction and evacuation, and maritime interdiction.
- **Logistics.** Unmanned systems are expected to transport supplies and perform maintenance tasks such as inspection, decontamination, and refueling. Future safety-related tasks will include munitions and material handling and combat engineering.
- **Force support.** The capabilities of unmanned systems may allow them to have a significant impact on medical sup-

port. They also could contribute to nuclear and bio-weapon forensics and contaminated remains recovery.

In March 2011, ONR issued a BAA seeking proposals on long-endurance unmanned undersea vehicle propulsion. The BAA states, “Greater breadth of mission profiles for current and future Naval UUVs require longer endurance stealthy propulsion systems that extend the current capability of 10–40 hours to several days or weeks.”

## ▶ VALUE PROPOSITION FOR DoD BENEFITS

For the unmanned vehicle application, mission accomplishment is generally the highest priority consideration in making vehicle design and systems decisions. Compared to other power options, fuel cells can provide improved mission capability.

- ▶ *Increased mission endurance.* Fuel cell systems can increase flight duration for UAVs; time on station for UAVs and UUVs; and range for all unmanned vehicles (“DoD Fuel Cell Activities” and “Other Fuel Cell Activities,” above.) Current power sources limit the ability of unmanned vehicles to support long-duration missions.
- ▶ *Reduced noise and heat signatures.* The sound and heat that conventional power systems produce sometimes limit how well unmanned vehicles can accomplish their missions. Fuel cells can be an attractive option for vehicles where sound or operating temperature are considerations.
- ▶ *Increased efficiency.* Fuel cells are significantly more energy-efficient than internal combustion engines, which improves mission duration.<sup>[70]</sup>

## ISSUES AND RISKS

Factors that weaken the value proposition of fuel cells for unmanned vehicles include:

- ▶ *Market size.* The fuel cell market for unmanned vehicle power systems, for both the government and the private sector, will expand. However, the total potential market and the rate of growth are unknown.
- ▶ *Costs.* Fuel cell systems are more expensive, and opportunities for reducing costs are constrained by low demand. The investment needed to achieve manufacturing efficiencies requires larger and more consistent demand. While cost may

be subordinate to mission capability, it is still an important factor in acquisition decisions.

- ▶ *Lack of design specifications and standards.*
- ▶ *Relatively little operating experience with fuel cell systems.* Because of a lack of experience, there are risks associated with service life and durability.

Government subsidies have been a key factor in the recent growth of commercial markets for fuel cells. The Chapter 2 section “Beyond Demonstration: The Future of Fuel Cells in DoD” addresses this and other issues relevant to DoD’s acquisition of fuel cells for multiple applications, including unmanned vehicles.

## ▶ RECOMMENDATIONS

The following factors were considerations in developing recommendations for fuel cell-powered unmanned vehicles:

- ▶ The potential mission benefits associated with using fuel cells
- ▶ The anticipated growth in unmanned vehicles employed for DoD operations
- ▶ The results of development and demonstration projects sponsored by DoD and others, which provide evidence of a positive value proposition associated with using fuel cells for DoD’s unmanned vehicles
- ▶ The lack of a mature, tested contracting model to enable efficient procurement of unmanned vehicles powered by fuel cells.

Recognizing the potential benefits of fuel cells for unmanned vehicles, in particular enhanced mission capability, the department should do the following:

- ▶ Monitor and participate in evaluations of fuel cell research, development, demonstrations, and market transformation. In particular, DoD should closely monitor development and demonstration projects for unmanned vehicle fuel cells. It should also track progress of fuel cells that are intended for commercial applications but have characteristics potentially suitable for unmanned military vehicles.
- ▶ Continue to support research, development, and demonstration of fuel cell systems for unmanned vehicles. Objec-



tives include improving performance, enhancing durability, reducing costs, and assessing the mission benefits of using fuel cells.

- ▶ Always consider fuel cells as an option for providing power whenever unmanned vehicles are designed and acquired. Ensure that design specifications and requirements do not constrain consideration of fuel cells or unduly favor legacy power systems.
- ▶ Require respondents to consider fuel cell power systems in solicitations for unmanned vehicles. This requirement can

be written into contracts with unmanned vehicle manufacturers and suppliers.

- ▶ Assess possible business models for and potential benefits of third-party financing of power systems for unmanned vehicles. The purpose is to ascertain whether fuel cell-powered equipment could be financially more attractive for DoD users.
- ▶ Leverage private-sector activities by conforming DoD designs and specifications for fuel cell systems to those for private-sector applications and requirements.

# CHAPTER 7

## CONCLUSIONS

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Government support, including by the DoD, has contributed to significant advances in fuel cell technology. Both public and private-sector projects are resulting in successful utilization of fuel cell systems. Having assessed the merits and readiness of fuel cells for DoD use, we determined that the department should proactively evaluate and acquire fuel cell systems for three applications:

1. *Distributed power generation.* Fuel cell systems can supply all or a portion of base load power, as well as heating and cooling needs. Used this way, fuel cells can increase energy efficiency and reduce operating costs, building energy intensity, and emissions.
2. *Backup power.* Military facilities are highly dependent on a vulnerable commercial power grid. Backup power systems eliminate risks resulting from grid disruption. As an option

for backup power, fuel cell advantages include reliability, lower maintenance, longer life, and lower emissions.

3. *Unmanned vehicles.* Growth is expected in DoD use of unmanned vehicles. As an option for powering these vehicles, and based on demonstration results, fuel cells have excellent potential to improve mission capability.

For these three applications, and real-world operating scenarios, we believe fuel cells are currently competitive with other technologies, or will be within the next 5 years. We recommend that the department develop and implement procurement models that increase the visibility of fuel cell options in competitive solicitations, allow more efficient acquisition of fuel cell systems, and take advantage of the potential benefits of third-party financing.



# END NOTES

## ► CHAPTER 1

- [1] Deputy Secretary of Defense William J. Lynn, III, 49th Annual Defense Environmental Awards Ceremony, The Pentagon, June 2, 2010.
- [2] U.S. Energy Information Administration, Annual Energy Review 2009, Figure 1.13.
- [3] “Charting a Course to Energy Independence,” presentation by Beth Shearer, GovEnergy Conference, August 9–12, 2009.
- [4] U.S. Energy Information Administration, Annual Energy Review 2009, Table 1.13.
- [5] “Department of Defense Facilities Energy,” presentation by Dorothy Robyn, Deputy Under Secretary of Defense, Installations and Environment, GovEnergy Conference, August 18, 2010.
- [6] Ibid.
- [7] National Energy Conservation Policy Act. Available at [http://www1.eere.energy.gov/femp/pdfs/necpa\\_amended.pdf](http://www1.eere.energy.gov/femp/pdfs/necpa_amended.pdf).
- [8] Energy Policy Act of 1992. Available at <http://www1.eere.energy.gov/femp/regulations/epact1992.html>.
- [9] Energy Policy Act of 2005. Available at [http://www1.eere.energy.gov/femp/pdfs/epact\\_2005.pdf](http://www1.eere.energy.gov/femp/pdfs/epact_2005.pdf).
- [10] Executive Order 13423. Available at <http://www1.eere.energy.gov/femp/regulations/eo13423.html>.
- [11] Energy Independence and Security Act of 2007. Available at <http://www1.eere.energy.gov/femp/regulations/eisa.html>.
- [12] Executive Order 13514. Available at <http://www1.eere.energy.gov/femp/pdfs/eo13514.pdf>.
- [13] Department of Energy and Department of Defense, “Concerning Cooperation in a Strategic Partnership to Enhance Energy Security,” Memorandum of Understanding, July 22, 2010.
- [14] Undersecretary of Defense for Acquisition, Technology and Logistics, Department of Defense Strategic Sustainability Performance Plan for FY10, August 26, 2010.

## ► CHAPTER 2

- [15] For more information on the various fuel cell types, see DOE, “Types of Fuel Cells,” at [http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc\\_types.html](http://www1.eere.energy.gov/hydrogenandfuelcells/fuelcells/fc_types.html).
- [16] Secretary of Defense Robert M. Gates, Opening Statement to the Senate Armed Services Committee, Dirksen Senate Office Building, January 27, 2009.
- [17] Report of the Defense Science Board Task Force on DoD Energy Strategy, “More Fight—Less Fuel,” February 2008.
- [18] Battelle Memorial Institute, “The High Volume Manufacture Cost Analysis of 5 kW Direct Hydrogen Polymer Electrolyte Membrane Fuel Cell for Backup Power Applications,” February 2011.

## ▶ CHAPTER 3

[19] Hydrogen fuel cell efficiencies vary by technology type; combined heat and power generation consistently achieves efficiencies above 80 percent. See DOE's Energy Efficiency and Renewable Energy's Fuel Cell Technologies Program website, <http://www1.eere.energy.gov/hydrogenandfuelcells/index.html>.

[20] "Cogeneration Case Studies of the DoD Fuel Cell Demonstration Program," presentation by Franklin H. Holcomb, Michael J. Binder, and William R. Taylor, U.S. Army Construction Engineering Research Laboratory (CERL), IQPC F-CELLS Stationary Conference, London, February 29, 2000; Robert J. Unger, Scott Kenner, Michael J. Binder, and Franklin H. Holcomb, Phosphoric Acid Fuel Cells Test and Evaluation, CERL, October 2004.

[21] Sandra Curtin and Jennifer Gangi, "The Business Case for Fuel Cells: Why Top Companies are Purchasing Fuel Cells Today," *Fuel Cells 2000*, September 2010.

[22] Ibid.

[23] Ibid.

[24] Department of Defense, *Base Structure Report FY 2010 Baseline (A Summary of DoD's Real Property Inventory)*, As of September 30, 2009.

[25] Report of the Defense Science Board Task Force on DoD Energy Strategy, "More Fight—Less Fuel," February 2008.

## ▶ CHAPTER 4

[26] DLA, Hydrogen Fuel Cell Pilot Program Overview. Available at <http://www.dlafuelcells.org/about/pilot-program-overview/>.

[27] Ibid.

[28] DOE, Energy Efficiency and Renewable Energy's Fuel Cell Technologies Program website, under "Financial Opportunities." Available at <http://www1.eere.energy.gov/hydrogenandfuelcells/recovery.html>.

[29] Sandra Curtin and Jennifer Gangi, "The Business Case for Fuel Cells: Why Top Companies are Purchasing Fuel Cells Today," *Fuel Cells 2000*, September 2010.

[30] NREL News Release NR-0611, "NREL Teams with Industry to Validate Methanol Fuel Cell Technology," February 18, 2011.

[31] Department of the Navy, OPNAV Instruction 4460.1A: Management of Material Handling Equipment (MHE) and Shipboard Mobile Support Equipment (SMSE) in Navy.

[32] K. Mahadevan, J. Zewatsky, and H. Stone, *Interim Report on the Market Opportunity Assessment of PEM Fuel Cell Applications at the Defense Logistics Agency*, Battelle Memorial Institute, November 2007.

[33] Ibid.

[34] National Fuel Cell Research Center, "PEM Fuel Cells: Value in California," University of California-Irvine, May 2008.

[35] F. Devlin and B. Gregory, "The Raymond Corporation, Commercialization of Fuel Cells for Forklifts," presentation at Fuel Cell and Hydrogen Energy Association Conference, February 2011.

## ► CHAPTER 5

- [36] Report of the Defense Science Board Task Force on DoD Energy Strategy, “More Fight—Less Fuel,” February 2008.
- [37] Sandra Curtin and Jennifer Gangi, “The Business Case for Fuel Cells: Why Top Companies Are Purchasing Fuel Cells Today,” *Fuel Cells 2000*, September 2010.
- [38] K. Mahadevan, Battelle Memorial Institute, “Market Opportunity Assessment of Direct Hydrogen PEM Fuel Cells in Federal and Portable Markets,” DOE Annual Program Review, June 2008.
- [39] Report of the Defense Science Board Task Force on DoD Energy Strategy, “More Fight—Less Fuel,” February 2008.
- [40] Department of Defense Strategic Sustainability Performance Plan for FY10. August 2010.
- [41] K. Mahadevan, H. Stone, K. Judd, and D. Paul, Battelle Memorial Institute, “Market Opportunity Assessment of Direct Hydrogen PEM Fuel Cells in Federal and Portable Markets,” FY08 Annual Progress Report for DOE.
- [42] National Fuel Cell Research Center, “PEM Fuel Cells: Value in California,” University of California-Irvine, May 2008.
- [43] [http://www.nrel.gov/hydrogen/proj\\_fc\\_market\\_demo.html](http://www.nrel.gov/hydrogen/proj_fc_market_demo.html).
- [44] Sandra Curtin and Jennifer Gangi, “The Business Case for Fuel Cells: Why Top Companies are Purchasing Fuel Cells Today,” *Fuel Cells 2000*, September 2010.

## ► CHAPTER 6

- [45] DoD FY09-34 Unmanned Systems Integrated Roadmap. Available at <http://www.acq.osd.mil/psa/docs/UMSIntegratedRoadmap2009.pdf>.
- [46] AeroVironment Press Release, “AeroVironment Puma Small UAS Achieves Record Flight of Over Nine Hours Using Fuel Cell Battery Hybrid System,” March 2008.
- [47] Protonex Press Release, “Protonex Awarded \$3.3 Million Contract to Develop a Deployable Fuel Cell Power System for Small Unmanned Aerial Vehicles,” March 18, 2009; Rob Coppinger, “AeroVironment’s Puma AE to Make Fuel Cell Flight,” *Flight International*, March 20, 2009.
- [48] Protonex Press Release, “Protonex Receives U.S. Air Force Contract Award to Extend Capabilities of Unmanned Aerial Vehicle Propulsion Systems,” May 8, 2009.
- [49] “SUAS Power System Considerations,” presentation by Ryan Miller, Air Force Research Laboratory, March 2011.
- [50] Naval Research Laboratory, “Surveillance Vehicles Soar on Fuel Cell Power,” *Spectra Magazine*, Fall 2010.
- [51] Adaptive Materials Press Release, “Adaptive Materials Achieves 12-hour, 40 Mile UGV Demonstration,” May 27, 2009.
- [52] John Keller, “Navy to Power Unmanned Underwater Vehicles with Fuel Cell Stack Technology from Delphi,” *Military and Aerospace Electronics*, March 1, 2010.
- [53] Hawaii Natural Energy Institute, “Research & Development/Fuel Cells.” Available at <http://www.hnei.hawaii.edu/rd.asp>.



- [54] Subir Roychoudhury, Dennis Walsh, Deryn Chu, and Erik Kallio, "Performance of a Diesel, JP-8 Reformer," presentation at Army 2008 SBIR Achievement Awards; Precision Combustion, Inc. Press Release, "PCI Awarded Army SBIR Phase I Contract for Ethanol Reforming," November 8, 2006.
- [55] UTRC Press Release, "UTRC Pioneers Fuel Cell-Powered Rotorcraft Flight," November 23, 2009.
- [56] Horizon Fuel Cell Technologies Press Release, "BlueBird Aero Systems, Horizon Unveil World's First Commercial Fuel Cell UAS," August 6, 2009.
- [57] Horizon Energy Systems Press Release, "Horizon's Fuel Cell Triples Flight Duration Capability of South Korean Close-Range UAV," November 9, 2010.
- [58] Horizon Energy Systems Press Release, "Russia's First AEROPAK Fuel Cell Flight Re-Opens Research in Hydrogen in Aviation," November 12, 2010.
- [59] Horizon Energy Systems Press Release, "Elbit Systems Successfully Completes Skylark I-LE UAS Test Flight with Horizon's New AEROPAK Fuel Cell," December 7, 2010. Available at <http://www.hes.sg/files/AEROPAKELBIT.pdf>.
- [60] Government Accountability Office, "Unmanned Aircraft Systems: Comprehensive Planning and a Results-Oriented Training Strategy Are Needed to Support Growing Inventories," GAO-10-331, March 26, 2010. Available at <http://www.gao.gov/new.items/d10331.pdf>.
- [61] Pacific Air Force Public Affairs Press Release, "Air Force Officials Use Global Hawk to Support Japan Relief Efforts," March 16, 2011. Available at <http://www.af.mil/news/story.asp?id=123247029>.
- [62] White House, Fiscal Year 2012 Budget of the U.S. Government. Available at <http://www.whitehouse.gov/omb/budget/Overview>.
- [63] Lisa Daniel, "Budget Balances Military Needs with Fiscal Restraint, Hale Says," *American Forces Press Service*, February 14, 2011. Available at <http://www.defense.gov/news/newsarticle.aspx?id=62808>.
- [64] Rob McIlvaine, "Gray Eagle UAS Program Expanding," *ARNEWS*, January 14, 2011. Available at <http://www.army.mil/-news/2011/01/14/50460-gray-eagle-uas-program-expanding/>.
- [65] "Kris Osborn, Army Expanding UAS Fleet, Speeding Up Delivery," *ASA(ALT)*, January 18, 2011. Available at <http://www.army.mil/-news/2011/01/18/50499-army-expanding-uas-fleet-speeding-up-delivery/>.
- [66] Michael Briggs, "Chief of Staff Sees UAS Role Expanding," *12th Flying Training Wing Public Affairs*, February 20, 2009. Available at <http://www.af.mil/news/story.asp?id=123136606>.
- [67] Ibid.
- [68] Federal Aviation Administration, "Aerospace Forecast Fiscal Years 2010-2030." Available at [http://www.faa.gov/data\\_research/aviation/aerospace\\_forecasts/2010-2030/media/Unmanned%20Aircraft%20Systems.pdf](http://www.faa.gov/data_research/aviation/aerospace_forecasts/2010-2030/media/Unmanned%20Aircraft%20Systems.pdf).
- [69] Teal Group Press Release, "Teal Group Predicts Worldwide UAV Market Will Total Just Over \$94 Billion," March 1, 2011. Available at [http://www.tealgroup.com/index.php?option=com\\_content&view=article&id=74:teal-group-predicts-worldwide-uav-market-will-total-just-over-94-billion-&catid=3&Itemid=16](http://www.tealgroup.com/index.php?option=com_content&view=article&id=74:teal-group-predicts-worldwide-uav-market-will-total-just-over-94-billion-&catid=3&Itemid=16).
- [70] Naval Research Laboratory, "Surveillance Vehicles Soar on Fuel Cell Power," *Spectra Magazine*, Fall 2010.

On the Back Cover:

From left to right: FCE fuel cell system, MCB Camp Pendleton, CA (Courtesy of PAO Camp Pendleton); Extended range vehicle, DLA Distribution Susquehanna, PA (Courtesy of Defense Logistics Agency); Plug Power fuel cell backup power system, Fort Jackson, Columbia, SC (Courtesy of LOGANEnergy); Mark II Talon robot, U.S. Navy Explosive Ordnance Disposal Mobile Unit 5, Detachment Japan, Yokosuka, Japan (U.S. Navy photo by Mass Communication Specialist Seaman Charles Oki/Released)



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